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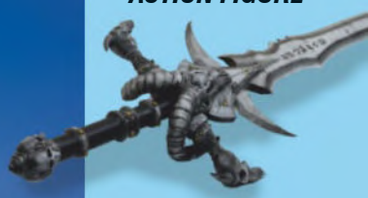
ARTICULATED ACTION FIGURE



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...from photographs

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Reviewed: Every type for every budget

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3D PRINTING

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THE PERFECT SET-UP • EXPERT TECHNIQUES

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PROFESSIONAL POLISH & PAINT TECHNIQUES

3D SOFTWARE TRIED & TESTED
FROM BEGINNER TO ADVANCED


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SCULPT YOUR CONCEPT. PREP YOUR MODEL.
SEND TO PRINT. ALL IN ZBRUSH.

Welcome

Bring your wildest designs to life today

3D printing is completely changing the world, and with 3D Make & Print you can start changing it too. From 3D-printed organs and prosthetics to tools that have been printed in zero gravity on the International Space Station, not to mention some of the incredible sculptures that redefine what it is possible to achieve in a physical medium, 3D printers are being used in almost every industry to transform the way that we do things and lead us into a bold new future.

What's more, this technology doesn't just belong to a select few – with desktop 3D printers now cheap enough to be within reach of every home, and open source projects like RepRap and Blender providing us with the hardware and software that we need to build 3D printers and make models ourselves, you can join the 3D printing revolution today and start breathing life into your own designs, making them a 3D-printed reality.

To help you get there, we've teamed up with 3D modelling and printing experts iMakr so that we can teach you all of the skills you'll need. Drawing on iMakr's wealth of experience and the amazing 3D models on MyMiniFactory, its curated platform for sharing 3D models in the community, we'll show you how to pick a 3D printer to use, how to set it up and run your first print, and how to create your own designs in the best 3D modelling software available. Excited? Let's make a start!

Gavin Thomas, Editor

3D MAKE & PRINT

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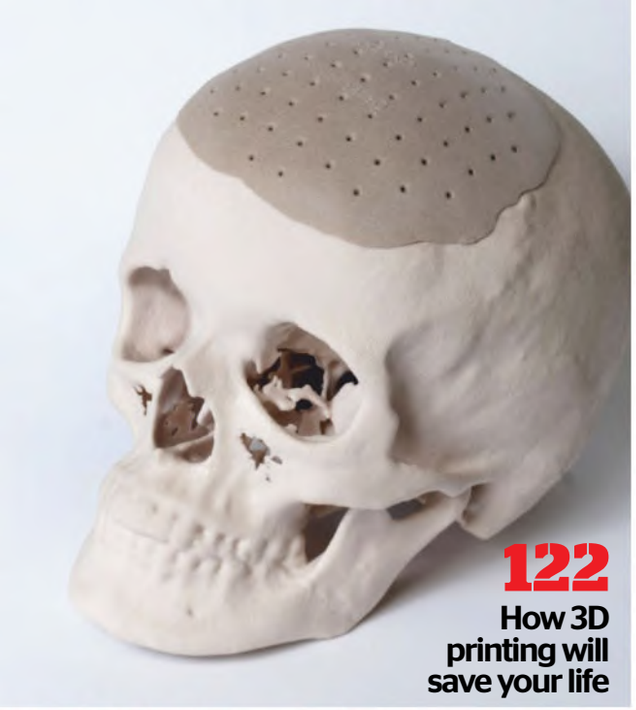

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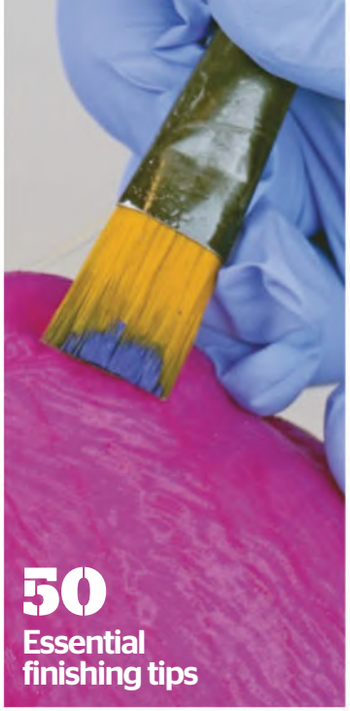

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100 FREE models

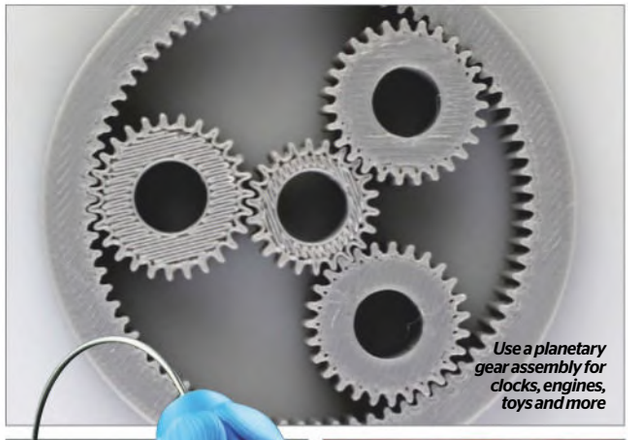
WANT TO TRY OUT 3D PRINTING RIGHT NOW? DOWNLOAD THESE FANTASTIC MODELS FROM THE EXPERTS AT MYMINIFACTORY

There's no need to worry if this is going to be your first time creating a 3D model – we have got plenty here to get you started! The very kind folk over at MyMiniFactory have shared a full hundred of their best 3D models with you, which you can download from FileSilo right now. Covering everything from fun figurines and desktop gadgets to working mechanisms, artistic sculptures and useful household items, there's a great range for you to explore. Learn more about MyMiniFactory over on page 108.





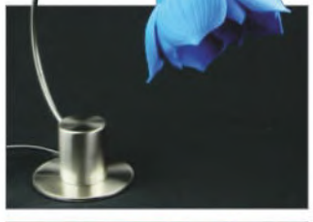








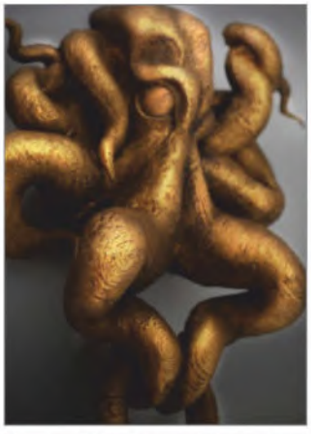


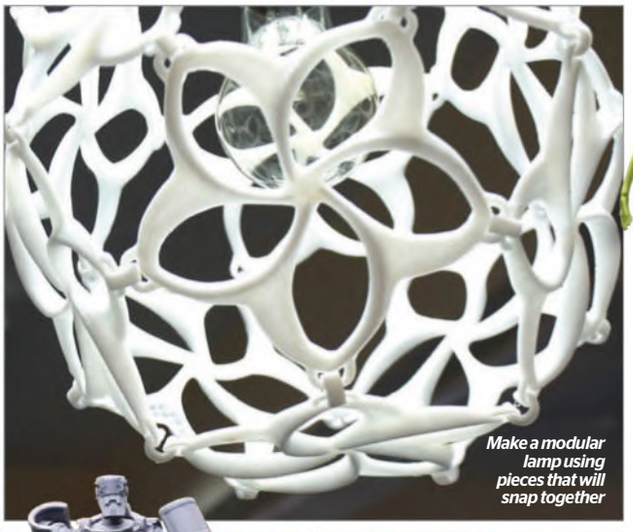




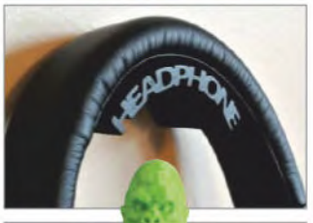


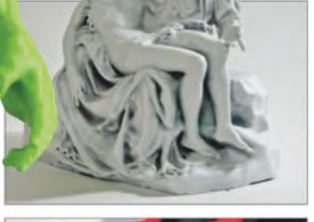


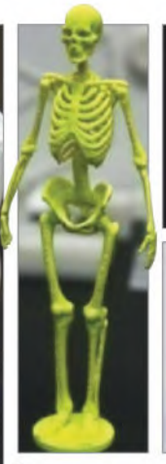


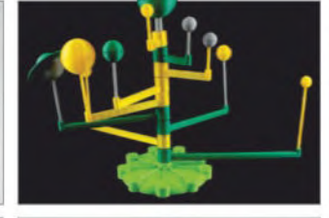






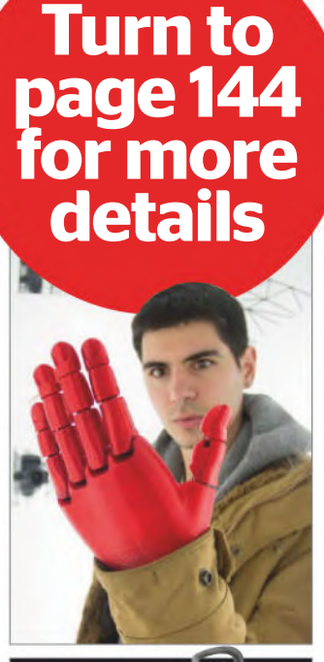









Turn to page 144 for more details

Neforak
Landis Fields
landisfields.tumblr.com

"Some messages are so important that they are 'hand' delivered by a species that is recognised as the couriers for most galaxies. These creatures are known as 'Neforaks', and for them this is more of a duty or way of life than a job."

Miniature People
Captured Dimensions
captureddimensions.com

● Tiny human replicas 3D-printed by Captured Dimensions, who use full-body scanning booths to capture subjects from every angle before creating lifelike models, right down to the shirt folds.

Oni Kabuto and Tombo Kabuto
Russ Ogi
russogi.com

"I combined my fascination for samurai armour and sci-fi/fantasy to create the *Bushido Fusion* pieces. After my files are 3D-printed, my prints undergo meticulous hand-crafting."

Spherical Harmonics – Vase Forms
Jonathan Keep
keep-art.co.uk

"I call myself an artist potter and, while my work has been described as sculptural, my interests are in the expressive visual language and traditions of pottery and making."

Digital Grotesque
Michael Hansmeyer &
Benjamin Dillenburger

digital-grotesque.com

● The first fully immersive, solid, human-scale, enclosed structure entirely 3D-printed out of sand, the structure measures 16 square meters and includes detail at the threshold of human perception. Every aspect is made with custom algorithms.

Sound Surface – Frank Zappa, The Torture Never Stops
Jonathan Keep
keep-art.co.uk

● "3D-printed clay from a self-built 3D printer. Layer by layer the pots are printed – like mechanical pottery coil building. After printing the ceramic is fired and glazed."

"Being able to work with the material of digital computation, in the form of Java computer language, I am able to grow my forms in virtual space"

Jonathan Keep
Sound Surface – Frank Zappa, The Torture Never Stops

3D Printed Speaker Enclosures

Evan Atherton

evanatherton.com

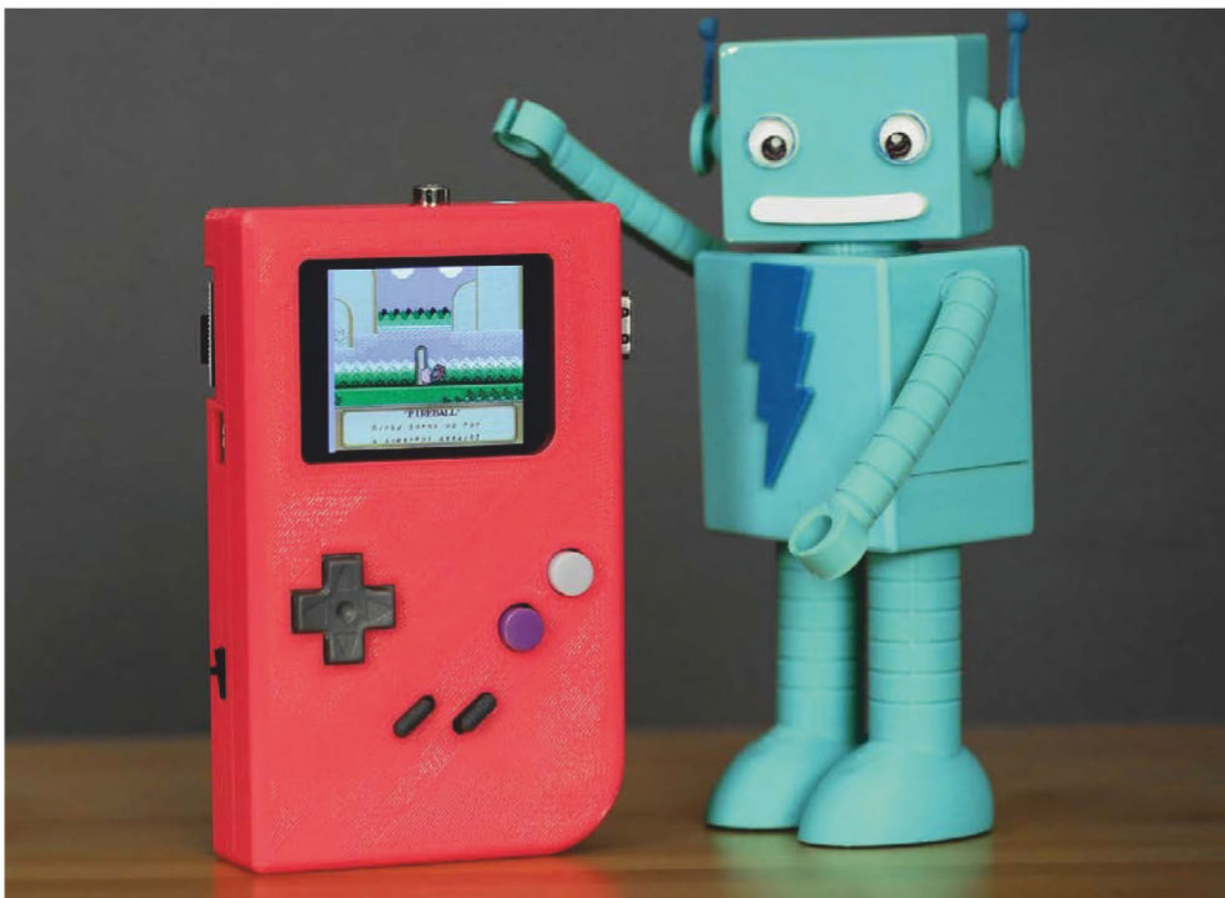
● "The Strategic Innovation team at Autodesk, led by Maurice Conti, designed these speakers to demonstrate the advantages that 3D printing offers today over traditional manufacturing techniques."

DIY Gameboy

Ruiz Brothers at Adafruit

learn.adafruit.com

● "Our most popular and fun project to date. This is one of the most fun projects you can make with a Raspberry Pi. It's a simple two-part enclosure design that can be modified to expand features."



"The piece juxtaposes the newfound reaches of our vision, discovery and technology against our vulnerability, privacy and humanity"

Joshua Harker
21st Century Self-Portrait

21st Century Self-Portrait
Joshua Harker
joshharker.com

● "Based on a 3D scan of my face and CT of my skull, coupled with a filigree aesthetic, the latest technologies have been applied to one of the oldest themes... the self-portrait."

Seed Bed
Jonathan Keep
keep-art.co.uk

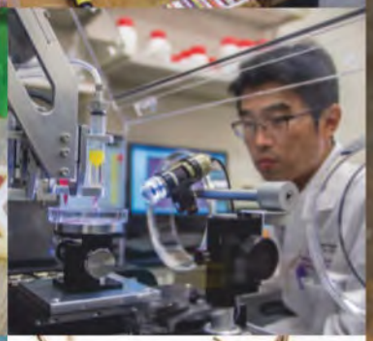
● The 'Seed Bed' project, printed using Keep's self-built 3D printer, was about highlighting our propensity towards natural forms and patterns, because we are part of that same natural world.

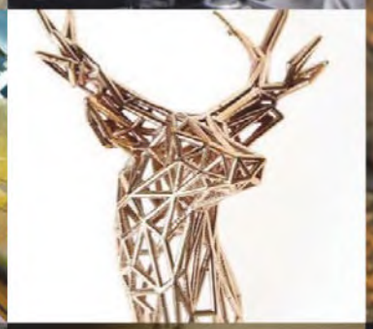
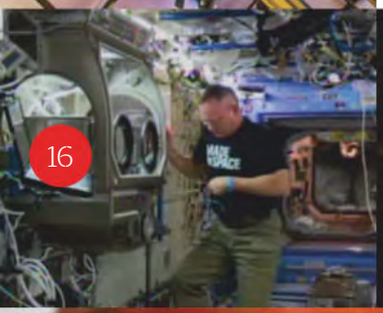
Butterfly Group Render
Captured Dimensions
capturedimensions.com

● The butterfly was 3D-scanned for a collaboration with designer Francis Bitonti, one of the artists who helped create Dita's von Teese's 3D-printed gown.





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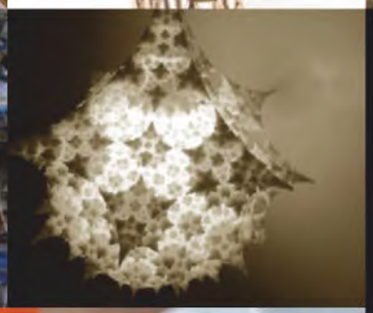






FanmBot


GREEN

12 WAYS 3D PRINTING CHANGED THE WORLD

FROM SPACE AND AGRICULTURE TO FASHION AND MEDICINE, EXPLORE ALL OF THE WAYS THAT 3D PRINTING IS SHAPING THE WORLD WE LIVE IN TODAY

It's astounding to think that up until just a few years ago, the idea of being able to print out any real, physical object you could imagine – all safely at home – was mostly considered the stuff of science fiction.

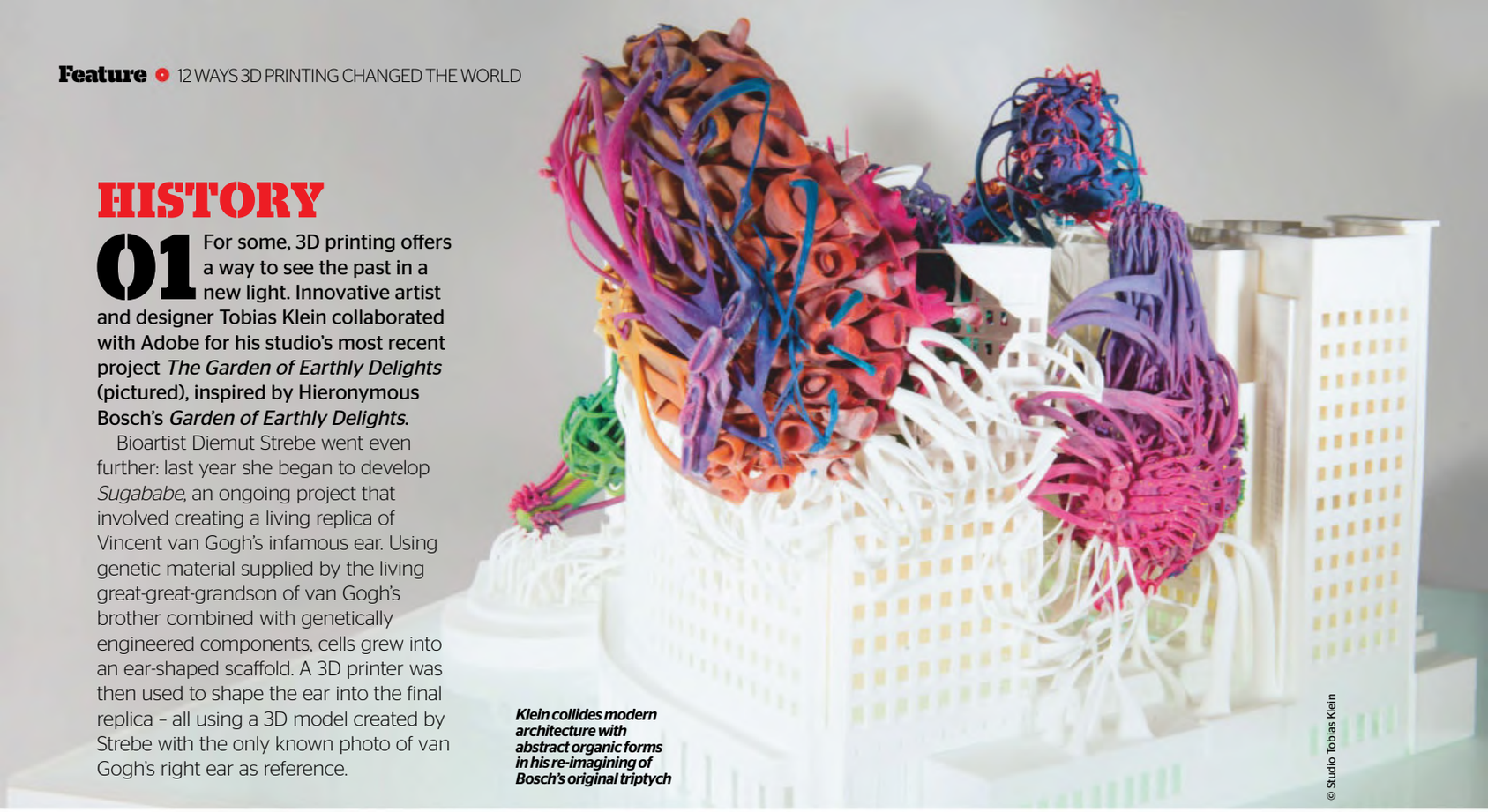
Though the earliest 3D printing technologies can be traced back to 1986, when the first patent was issued for an SLA apparatus invented by Charles Hull, it was not until January 2009 that the first commercially available consumer 3D printer, the BfB RapMan, was put up for sale. The move was like the start of an avalanche. Soon, projects like Z Corp's Spectrum Z510, RepRap and MakerBot's Cupcake CNC kit began to change the world for good. 3D printers could be bought to use in anyone's living room or office, and the very idea of 3D printing became common knowledge for the very first time. For many, it marked the start of the next industrial revolution.

3D printing objects at home, however, is only the very tip of the iceberg. Fast-forward to today and 3D printing has been used to the develop the world's first fully drivable 3D-printed car, made up of 212 layers, and has enabled astronauts to quickly print much-needed tools on the International Space Station. One day soon, it could herald the start of a whole new way of farming, making clothes or building homes. We could even see the dawn of fully functional 3D-printed human organs. Let's take a look at the industries and innovations shaped by 3D printing today.

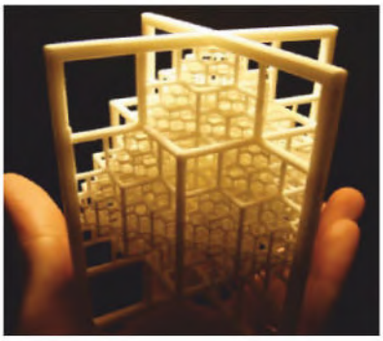
HISTORY

01 For some, 3D printing offers a way to see the past in a new light. Innovative artist and designer Tobias Klein collaborated with Adobe for his studio's most recent project *The Garden of Earthly Delights* (pictured), inspired by Hieronymous Bosch's *Garden of Earthly Delights*.

Bioartist Diemut Strebe went even further: last year she began to develop *Sugababe*, an ongoing project that involved creating a living replica of Vincent van Gogh's infamous ear. Using genetic material supplied by the living great-great-grandson of van Gogh's brother combined with genetically engineered components, cells grew into an ear-shaped scaffold. A 3D printer was then used to shape the ear into the final replica – all using a 3D model created by Strebe with the only known photo of van Gogh's right ear as reference.



Klein collides modern architecture with abstract organic forms in his re-imagining of Bosch's original triptych



Brunet brings mathematics to life by giving physical forms to abstract equations

ART AND DESIGN

02 One of the most immediately obvious benefits of 3D printing at a consumer level has been to the world's artists and designers. Desktop 3D printers have better resolutions and build volumes than ever before, and what was once a choice between ABS or PLA has quickly opened to a huge variety of colours and options. Any artist interested in 3D-printing their work is spoiled for choice.

"3D printing will definitely play an important role in the world of art going forward," says artist Jérémie Brunet. Fascinated with fractals since the age of 13, Brunet jumped at the chance to use 3D printing to actually hold one. "Having played for many years with fractals on my computer screen, giving them substance via 3D printing was somehow inevitable," he laughs. "The main challenge is that what is interesting in fractals is their infinite level of detail, and of course 3D printing has to comply with the rules of physics and with a maximum level of detail.

"In general, it involves the export of voxel stacks from Mandelbulb3D to start with," Brunet explain. "Stacks are then combined into a triangle mesh using Fiji's marching cubes algorithm. There's post-processing and optimisation in Meshlab, and final checks and repairs in Netfabb."

FASHION AND JEWELLERY

03 As liberating as the advent of consumer 3D printing was for artists, it has arguably been even more life-changing for jewellery designers. New printer types such as the B9Creator use a powerful Digital Light Processing projector to shine an image onto a resin, curing it into a solid to make very tiny, high resolution final prints that are perfect for jewellers. This means that designing and casting unique jewellery has become easier, more iterative and more accessible to the general population than ever before.

"The product development and manufacturing pipelines have changed since I started using 3D printers," says jewellery designer Mark Bloomfield. "There's an immediacy now which is very difficult to achieve with traditional forms of manufacture. I can get new samples in as little as three days and production doesn't take much longer, so you can iterate and supply while the idea is still fresh and exciting."

Using Blender, Bloomfield aims to create jewellery that truly takes advantage of the 3D printing process by being unlike anything you could normally find in a shop. It's entirely customisable – charms on his latest *Pixel Trellis Runway Necklace* can be removed, repositioned or twisted to turn on flashing LEDs inspired by landing lights on a runway.

Generative design studio Nervous System has also taken advantage of 3D printing processes to invent whole new products. As well as selling jewellery and housewares, it has developed a new system for 4D printing called 'Kinematics', which creates complex, foldable forms with flexible structures straight from the printer – no assembly required. Everything from jewellery to clothes has been created with the system, and Kinematics apps even allow users to develop their own perfectly sized designs to order or 3D-print at home.

The future of 3D printing in fashion is set to become even more incredible. Currently being prototyped by biomedical/mechanical engineer Aaron Rowley and his team is project Electroloom, a consumer 3D printer for fabrics. It could allow clothes to be shared, downloaded and printed anywhere.

Kinematics Dress and Tetra Kinematics 6e in black by Nervous System. Photography: Steve Marsel. Design: Jessica Rosenkrantz and Jesse Louis-Rosenberg. http://n-e-r-v-o-u-s.com

"I can get samples in as little as three days and production doesn't take much longer, so you can iterate and supply while the idea is still fresh"

Digital detail on a printed model can be revealed by looking through the window of a tablet or smartphone

© INITION

AUGMENTED REALITY

04 They may seem like very different things, but 3D printing has also been used with another recently repopularised technology: augmented reality.

When the team at Inition were approached by architects Zaha Hadid to use augmented reality to enrich architectural prints, the results of combining the two technologies were highly successful. "It allowed the expression of complex concepts through easily accessible means, allowing the user to explore the subject while navigating in a wholly intuitive manner," comments Alex Lambert, lead creative at multidisciplinary production company Inition.

"Personally, I would like to do something more creative," he adds. "An abstract piece, such as a music video or a live streaming piece, compositing real people within a 3D-printed stage or set."

FOOD

05 Food production is another area that has garnered a significant amount of attention since the advent of consumer-level 3D printing. In theory, all you have to do is 3D-print edible products instead of plastic and it could transform the food industry. Barilla, Hershey's and Modelez International are just a few of the worldwide food brands currently exploring this potential.

Today, 3D printers have been modified to create a wide variety of customisable foods, including sugar, ice cream, pasta, chocolate and even pizza. Foodini from Natural Machines, which is to be released for £830 later on in 2015, is one such printer.

To use the Foodini, which has been engineered to take on the time-consuming parts of food preparation, the user first simply chooses what recipe they want to print from the Foodini's Internet-connected touchscreen or from their own computer or mobile device. Foodini then gives a breakdown of instructions for the various ingredients that should be prepared and placed in its stainless steel capsules, which are reusable and easy to clean. Next, the edible ingredients previously loaded into the machine are squeezed out of the capsules – then it's ready to cook and eat.

With a Foodini printer, you can get really creative with your presentation

© Natural Machines

Print Green is sowing the seeds of a new kind of precision gardening

"An obvious application was planting seeds, and tending to them in a precise way"

AGRICULTURE

06 Why stop at 3D-printing your food when you can help grow it in the first place?

With Print Green, students Maja Petek, Tina Zidanšek, Urška Skaza, Danica Rženiènik and Simon Tržan from the University of Maribor aimed to link art, nature and technology. Together, they developed a CNC machine designed to print a mixture of soil, water and seeds in order to create 3D prints that would turn green over time.

Meanwhile, the open source FarmBot is set to use similar ideas to create food for everyone. "I see incredible progress in the 3D printing industry and figured there had to be other ways in which the technology and the open source philosophy could be applied," says Rory Aronson, the project organiser behind FarmBot. "An obvious application to me was planting seeds, and tending to them in a precise way."

As well as allowing for precision CNC farming with millimetre accuracy, FarmBot can also be set up, customised and controlled directly from a web browser. It ships with the some of the most common electronics of the DIY world: the Raspberry Pi Model B+ and the Arduino Mega 2560.

"In five years time, I hope there is a vibrant community surrounding FarmBot technology," Aronson tells us. "I hope to see that the technology is significantly refined such that it is very functional for a wide range of use cases, such as vertical, hydroponic and experimental farming, as well as soil-based, small-scale applications."

© Print Green

VEHICLES

07 Earlier this year, Local Motors made headlines at the 2015 North American International Auto Show when it debuted the world's first fully drivable 3D-printed car by printing and assembling it live on the show floor. Called the Strati, the car is made up of less than 50 parts – the average vehicle has 2,000 parts – and it takes 44 hours to print the 212 layers needed to create one.

"The ultimate goal Local Motors has for its 3D-printed cars," reveals Local Motors' Jamie Hobbs, "is for consumers to be able to come into one of the factories and say 'I want a four-seater with this type of body style and colour', and Local Motors to have it available to them within a couple of days."

Another breakthrough vehicle design was the Urbee (URBan Electric with Ethanol as backup), an incredible working prototype of a daily use car with a 3D-printed body that works solely through renewable energy. "Ever since I started my design company in 1984, my small group has always made models of our designs out of wood, foam, plastic and more," explains Jim Kor, president of KOR EcoLogic. "As 3D printing became more and more economic, we adopted that technology, until it was fully integrated in our process."

Urbee 2 is in development and will be almost entirely 3D-printed, as well as the greenest car on Earth

© KOR EcoLogic Inc. www.URBEE.net

The Canal House in Amsterdam is a continually evolving building, adapted with new 3D-printed parts

© DUS architects

ARCHITECTURE

08 Soon, we could even start to see 3D-printed cities, and have an amazing new solution to solving homelessness or creating rapid housing for disaster-stricken communities. Chinese company Winsun has already showcased ten £3,200 concrete houses that were all 3D-printed in a day, and even unveiled a 3D-printed 1,100 square meter villa and five-storey apartment building created earlier this year.

Meanwhile, Amsterdam firm DUS Architects has now publicly opened its 3D printed Canal House – an exhibition, research and building site for 3D printing architecture. The entrance fee is part of what helps finance the house, and as it is constantly under construction, this means anyone can watch as the team continue 3D-printing and see the Canal House in the very heart of the city change and grow.

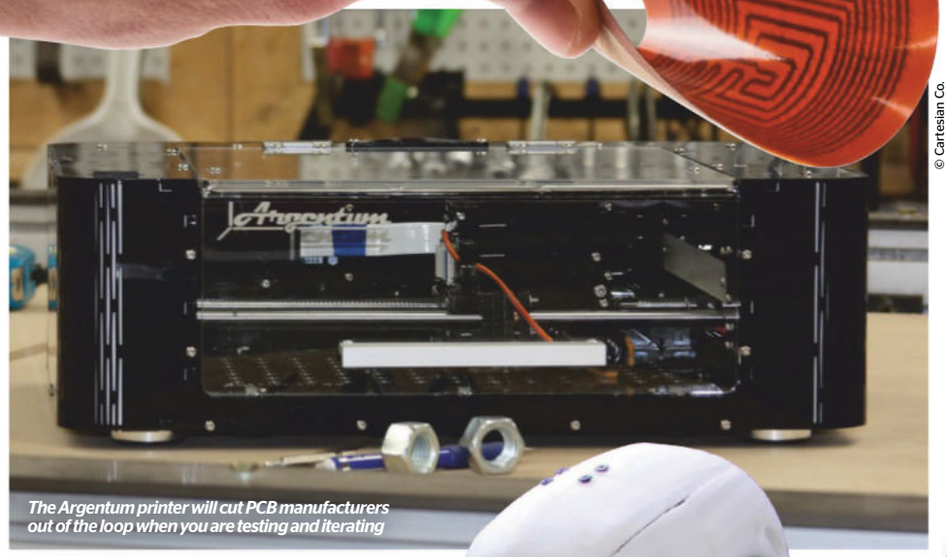
The printer DUS Architects developed for the project is called the KamerMaker. "The KamerMaker works in exactly the same way as the Ultimaker, the small desktop 3D printer, as it is simply an upscaled version," reveals Tosja Backer, expo manager of the Canal House at DUS Architects. The team is currently printing with bioplastics and aim to print with a material that is sustainable while still sturdy and stable – perfect for printing buildings at high levels of detail that are customised to the commissioner.

"The Voxel8 will enable users to co-print thermoplastics and highly conductive silver inks"

ELECTRONICS

09 Upcoming desktop printers will disrupt the design and manufacture of electronics. The Voxel8 printer, which is expected to start shipping in late 2015, will enable users to co-print matrix materials such as thermoplastics and highly conductive silver inks to produce customised devices such as electromagnets and working electromechanical assemblies.

Cartesian Co's flagship Argentum printer, available as a kit or fully assembled, can print circuits in minutes and enables users to print them on paper, fabric or anything else that fits. Users can then even solder components straight onto the board as they normally would, even when on paper.



The Argentum printer will cut PCB manufacturers out of the loop when you are testing and iterating

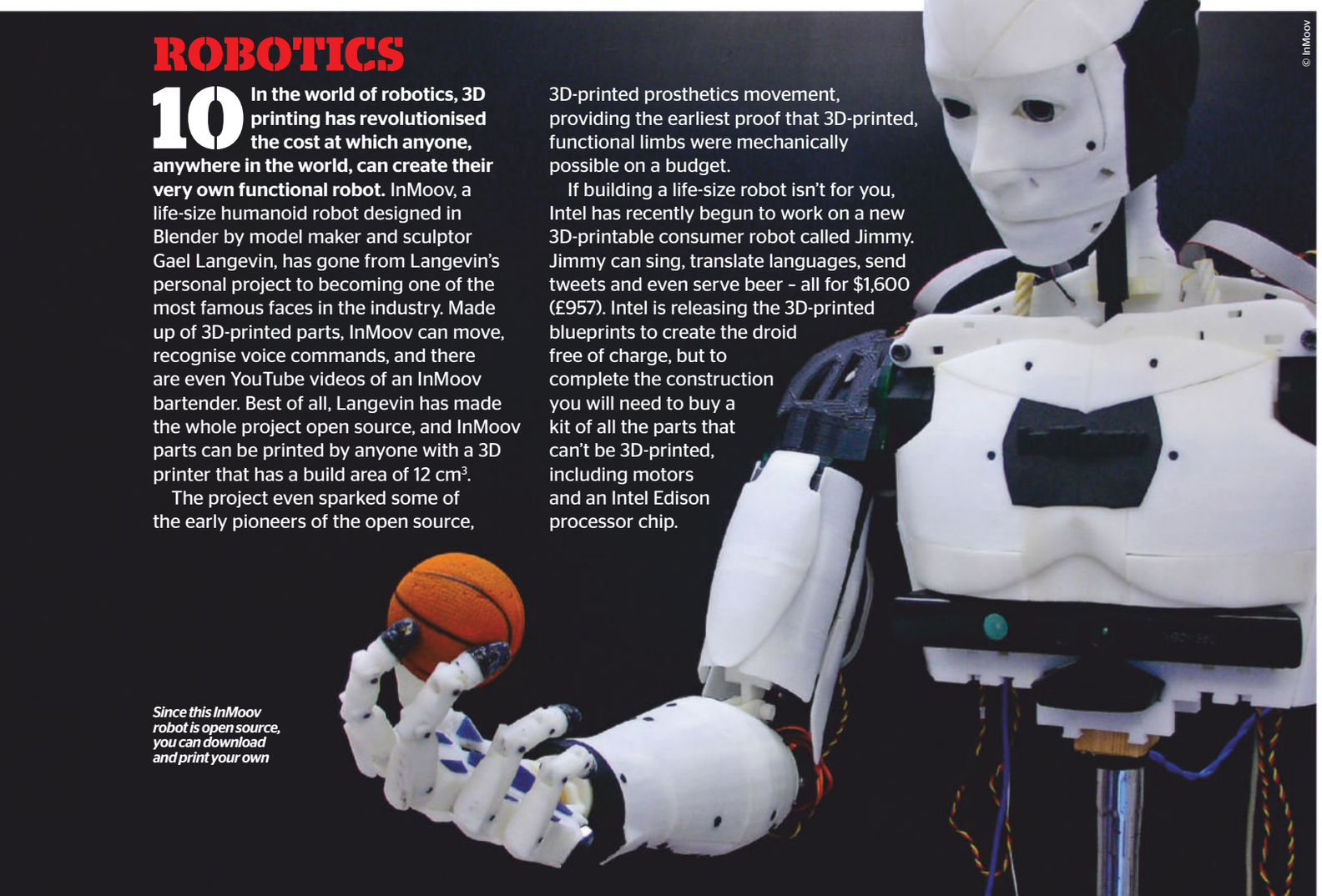
© Cartesian Co.

ROBOTICS

10 In the world of robotics, 3D printing has revolutionised the cost at which anyone, anywhere in the world, can create their very own functional robot. InMoov, a life-size humanoid robot designed in Blender by model maker and sculptor Gael Langevin, has gone from Langevin's personal project to becoming one of the most famous faces in the industry. Made up of 3D-printed parts, InMoov can move, recognise voice commands, and there are even YouTube videos of an InMoov bartender. Best of all, Langevin has made the whole project open source, and InMoov parts can be printed by anyone with a 3D printer that has a build area of 12 cm^3.

The project even sparked some of the early pioneers of the open source, 3D-printed prosthetics movement, providing the earliest proof that 3D-printed, functional limbs were mechanically possible on a budget.

If building a life-size robot isn't for you, Intel has recently begun to work on a new 3D-printable consumer robot called Jimmy. Jimmy can sing, translate languages, send tweets and even serve beer – all for $1,600 (£957). Intel is releasing the 3D-printed blueprints to create the droid free of charge, but to complete the construction you will need to buy a kit of all the parts that can't be 3D-printed, including motors and an Intel Edison processor chip.



Since this InMoov robot is open source, you can download and print your own

© InMoov

MEDIA AND ENTERTAINMENT

11 From helping create the stop motion facial movements in *The Boxtrolls* to making the printing of mini 3D self-portraits at supermarkets a reality, 3D printing has hugely expanded as a technology in media and entertainment.

"I set up Zealot Miniatures four years ago, for a little extra beer money, while starting university, studying CGI Modelling," explains Eddie Fisher. By modifying printers to be able to create work in layers down to 6 microns (0.006 mm), Fisher has seen his beer money project grow into a thriving business. "Customers buy the models for board games or to paint, as minute artworks," he reveals. Incredibly, because these tiny miniatures are made at such a high resolution, one can take up to three days to print.

Legacy Effects, a special effects studio in Southern California that has created work for films such as *Pacific Rim*, the *Iron Man* franchise and *The Avengers*, has been embracing 3D printing for nearly a decade. The team has a full 3D printing lab with nearly ten machines, and they're not just used for rapid prototyping of parts. In *Robocop*, versions of the suit used in the final movie were made up of as much as 90% Stratasys 3D-printed parts.

"Customers buy the models for board games or to paint, as minute artworks"

© Captured Dimensions

Turn to page 98 to find out how to create your own miniature figurines from real photos

Incredibly, the team found no significant print failures during their testing of the Zero-G Printer

SPACE

12 It may seem like sci-fi, but 3D printing in space has become a reality for astronauts on the ISS.

Just last year, NASA mission control did what was previously thought to be impossible: they emailed a working socket wrench to space. To use the wrench, astronauts then printed the CAD file with an experimental zero-gravity 3D printer built by engineers at Made In Space under a joint partnership with NASA MSFC, contracted as the '3D Printing in Zero-G Experiment'. The wrench, which took four hours to complete, was the very first object to have been designed on the ground before being sent digitally into space.

The process hasn't been easy, especially with the challenges of successfully 3D printing without the natural gravity that helps deposit layers on Earth. The Made In Space team had to ensure that thermal processes were adjusted and extreme safety precautions were in place so the printer posed no threat to astronauts.

By successfully ushering in a new age in which assets are manufactured directly in space instead of launched from Earth, Made In Space's team has achieved something truly exciting. The technology could seriously accelerate and broaden space development while also showcasing a critical logistical solution in establishing a sustained human presence in space. At the time of writing, 25 parts have now been manufactured off-world, with many more planned.

GET STARTED WITH 3D PRINTING

3D printing has become a hot topic recently and many people are beginning to realise the benefits and possibilities that it has to offer. With more people looking to take the leap and invest in, or start using one, it seems pertinent to address the questions of what exactly a 3D printer is and does.

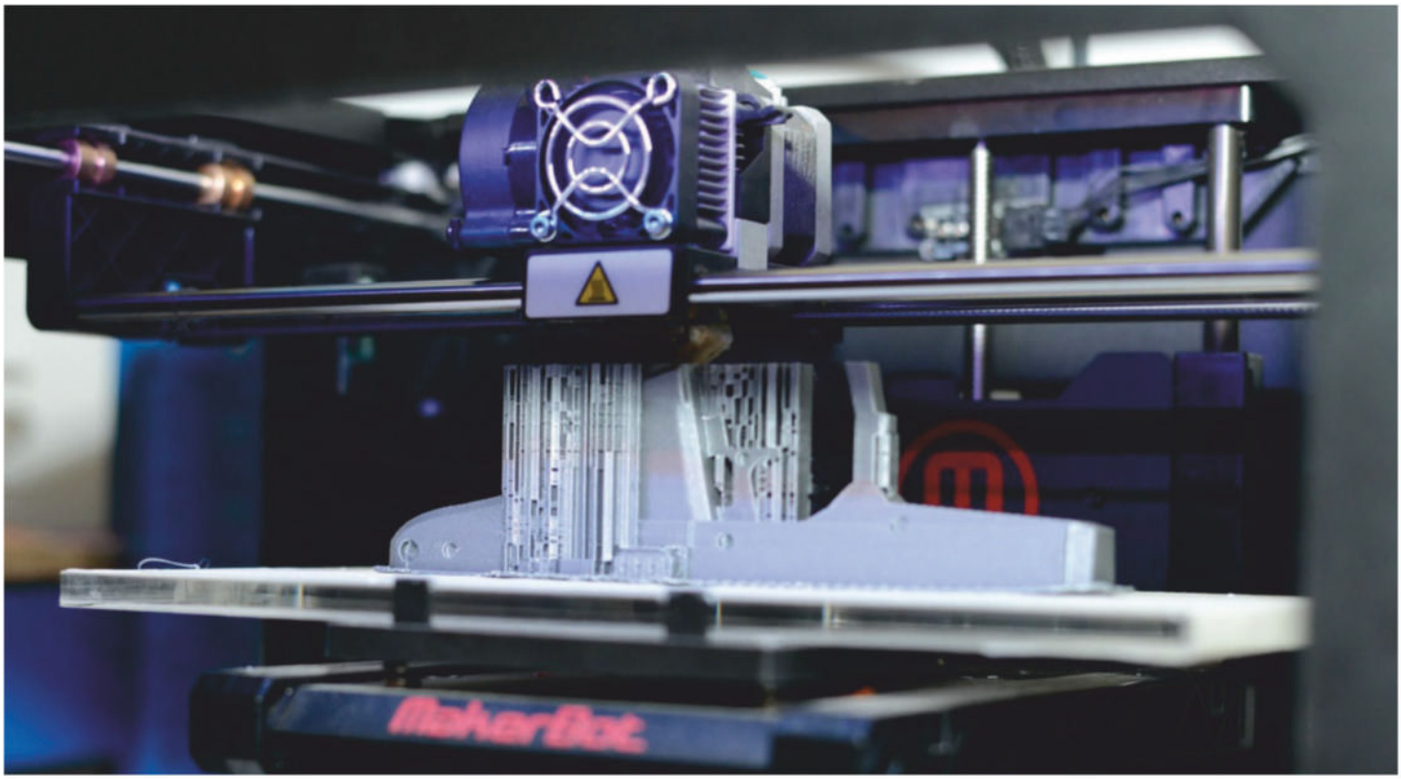
3D printing is the process of building something layer by layer. It doesn't matter which form of 3D printing or which technology is being used, this fundamental principle stays constant. There is a general misconception that all 3D printers are the same thing – this is not the case at all. Each printer and process will come with their own challenges and key principles that need to be followed to get the best out of them. It's impossible to show you a single machine and explain what the components do as each process is different. Some printers build upside down, some anywhere in a 3D space, while others only on a flat bed. Some

printers build from liquid resin, others from powder or molten plastic. Which of the several main processes used for 3D printing will be the most applicable for the model or part that you wish to create will depend on the nature of your project.

There are a lot of people out there that think all 3D printing is the same thing or that there is only one type. This is partly due to the popularity of FDM printing and also because it is the most interesting form of printing to watch. Some of the best known brands like Ultimaker and MakerBot create FDM printers and they have helped to make the 3D printing industry as popular as it is today.

However, despite being the most popular method, FDM doesn't suit every model that people wish to print. Other technologies can sometimes be better suited due to the level of detail you wish to achieve, the amount of time you have to create your model, the surface finish you want to accomplish, or the number of parts that you want make simultaneously.

Don't forget that 3D printing requires some form of 3D data to send to it. This can come from either a CAD (Computer Aided Design) file, or the data from a 3D scan. No, you can't print from a 2D picture or the item itself, the technology to be able to do that doesn't exist at the moment. After all, you wouldn't walk into a photo processing shop and ask them to print the picture without giving them your SD card or the camera itself!



HOW DO 3D PRINTERS WORK?

NEED TO PRINT A PLASTIC HINGE, A METAL COG OR EVEN AN ENTIRE ELECTRONIC CIRCUIT? THERE'S A 3D PRINTER FOR THE JOB!

3D printing is also called additive manufacturing because it works by adding new material, as opposed to a computer-controlled lathe or laser cutter, which removes it. The earliest system, called stereolithography, dates back to 1986 and uses a resin that hardens on exposure to ultra-violet light. The printer scans a beam of UV light over the surface of a bath of the resin to create a thin layer of plastic. The model is then sunk slightly into the bath so that the laser can add a new layer on top. Selective laser sintering (SLS) works in a similar way to print with metal. The printer shakes a thin layer of metal powder onto the print bed and a high-power laser fuses the powder at certain points to create solid metal. Powder jet printers use plaster of Paris instead of metal, and bind it together using a print head that squirts a special glue.

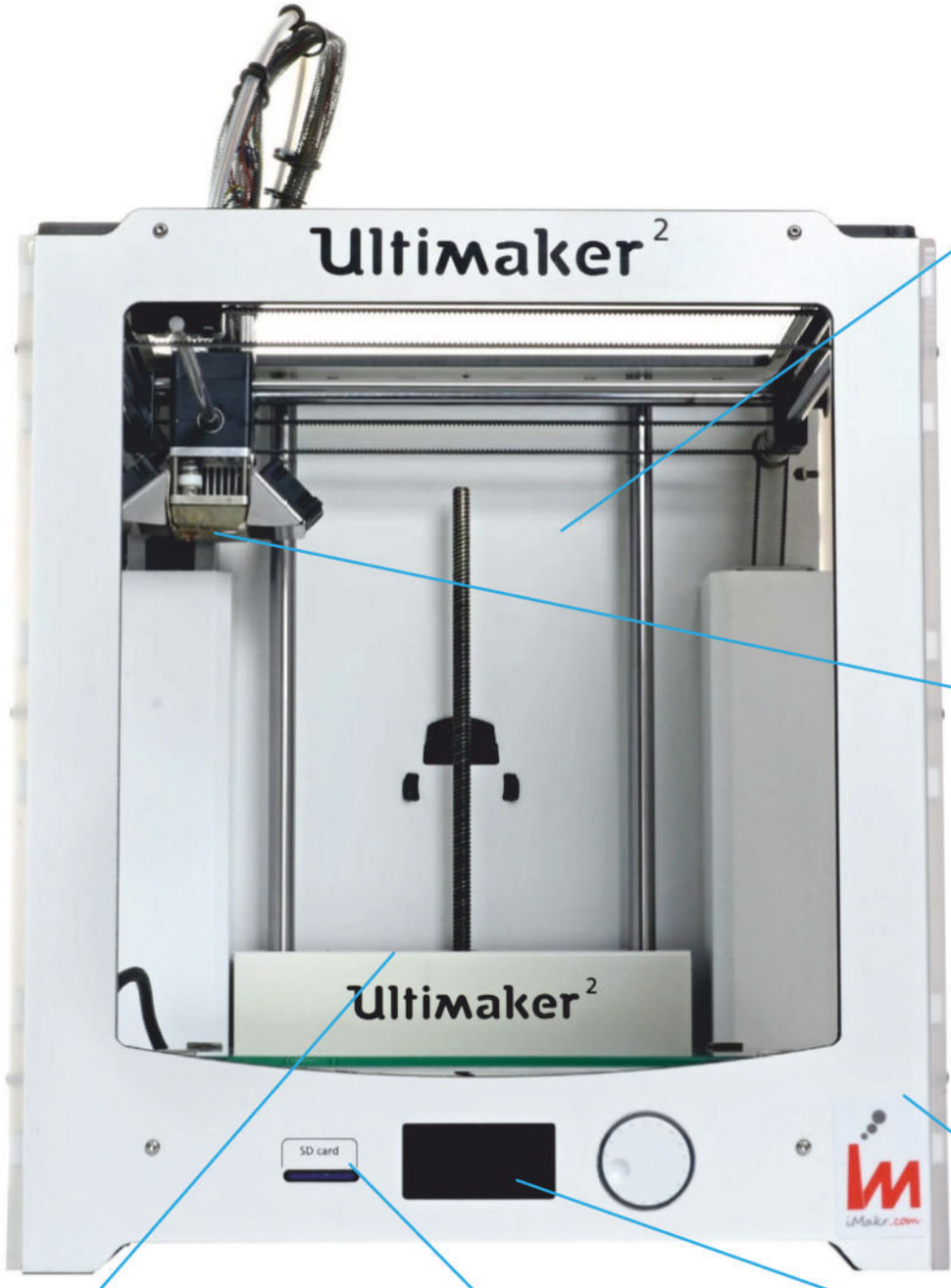
But for the home user, the most practical 3D printing technology is fused deposition modelling, or FDM. Plastic wire is fed from a spool through a heated nozzle to melt it. The model is printed on a stage, or print bed, which is moved very precisely under the print nozzle to trace out the shape of the model. It's like a very fine, computer-controlled, hot glue gun. FDM can't print overhanging pieces without including temporary struts to connect them to the main model, but most design software will include these automatically and they can be cut away afterwards using a modelling knife.

The strength of the finished piece depends partly on the type of plastic filament you use, but FDM models are always weakest in the vertical axis because the bond between each horizontal layer isn't nearly as strong. More expensive printers that use heated build chambers can help with this, and recently a company called MarkForged has developed an FDM printer that can embed carbon fibre into a plastic model to produce pieces that are as strong as aluminium.

Home 3D printing is just starting to boom. In the next few years, the price of FDM printers will drop, to rival 2D inkjet printers today. But you will also be able to print with a wider and more exotic range of materials. Already, manufacturers are printing electronic circuits using an aerosol spray of powdered semiconductor materials. Optomec in New Mexico has developed wallpaper with LED lighting printed directly onto the pattern, and British firm GKN Aerospace is printing physical buttons and switches using a piezoresistive ink that changes its electrical resistance when squeezed. For home electronics projects, you will soon be able to print your own circuit boards to connect to an Arduino or Raspberry Pi.

"The strength of the finished piece depends partly on the type of plastic filament you use"

ANATOMY OF A 3D PRINTER



©MakerBot

BUILD CHAMBER

Enclosing the print area can improve the quality of the finished print, by allowing better control of the temperature around the model, so the filament solidifies evenly.


©MakerBot

EXTRUDER

A stepper motor feeds the filament through a heated nozzle at a precise rate. The nozzle melts the plastic just enough so that it sticks to the growing model.

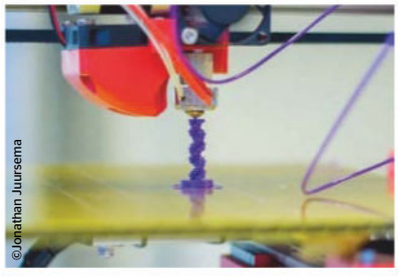

©MakerBot

FILAMENT

The 'ink' for a 3D printer. ABS and PLA are the most common plastics but there are also filaments that conduct electricity, or change colour depending on temperature.

PRINT BED

The maximum size of the model is determined by the size of the print bed. Many printers use a heated bed to help the first layer of plastic to stick.


©Jonathan Juursema

DATA INPUT

To transfer the print instructions that describe the model, 3D printers accept data from an SD card, via a USB device, or directly from a connected computer.

©MakerBot

DISPLAY

An LCD screen shows the progress of the build and allows you to adjust some settings. Budget printers sometimes omit this option solely for computer control.

©MakerBot

THE CHEAPEST, EASIEST PRINTER

FDM PRINTERS WORK BY PUTTING DOWN EXTRUDED MATERIAL LAYER BY LAYER UNTIL THE ENTIRE MODEL IS COMPLETED

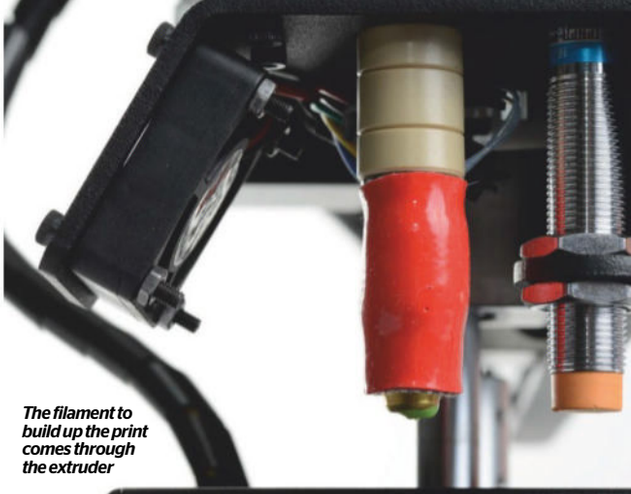
FDM (Fused Deposition Modelling) printers can use a variety of materials including ABS plastic, rubber and even wood pulp. Each material has its own strengths and weaknesses and thought should be given to the properties of each before choosing one for a project. FDM printers are able to print in multiple materials at the same time, which can mean multiple colours or that one nozzle will deposit a support material for the other one to build upon (this is often used when the model has 'overhangs' of some from). This support material is then removed when the finished part has cooled and hardened.

The CAD file that is loaded into the printer is sliced into layers, the thickness of which depends on the layer resolution of the machine (this is printer and setting dependant). The nozzle then extrudes the chosen material onto a bed, which, depending on the material, may need to be heated to avoid warping or even cracking due to the melting and rapid cooling process. Support material is normally generated automatically where the printer thinks it will need it to build upon for future layers. These are called overhangs, and are simply parts of the model that poke out where no material has been put down previously. Imagine printing the letter T, for example; the central part is easy to make but to put the top on it there would need to be something underneath to support the melting plastic. Otherwise it would just drip to the floor. Of course this does depend on the orientation of the part and certain software out there will decide on the best and most efficient way of printing something so you don't have to.

"Each material has its own strengths and weaknesses, and thought should be given to their unique properties when planning"

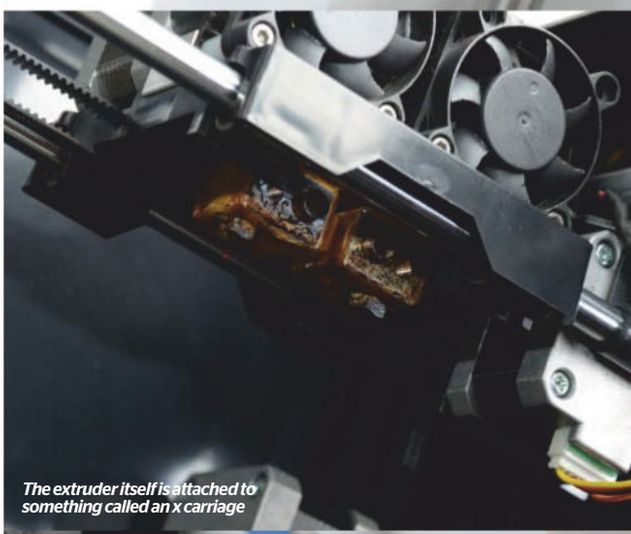
WHY USE AN FDM PRINTER?

FDM printing has a wide variety of uses. Because of its simplicity and the amount of information out there, FDM printers are the most common variety of desktop printers available. This means that most people who want to buy a 3D printer for their home will be looking into an FDM model. FDM is also the easiest form of printing to understand and get to grips with while you explore the world of 3D printing. Before you take the leap, though, make sure you've done your research: certain printers will fit your needs better than others. It is also worth considering the communities that have sprung up around these printers and taking their feedback and knowledge on board.

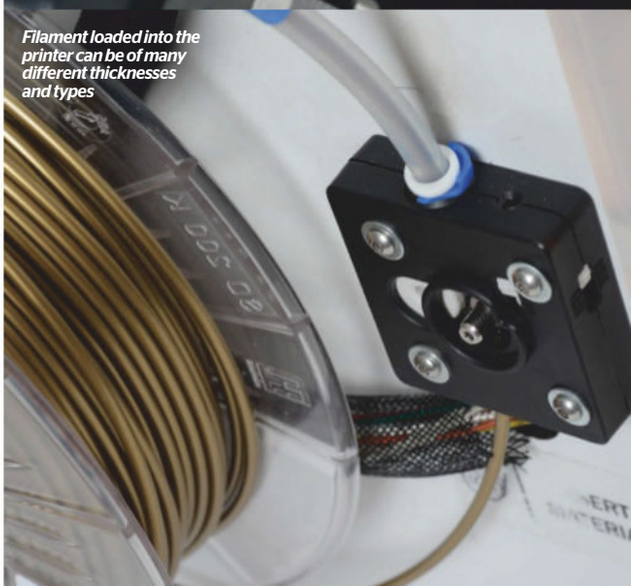


The filament to build up the print comes through the extruder

Different motors are used to move the extruder along the X, Y and Z axes



The extruder itself is attached to something called an x carriage



Filament loaded into the printer can be of many different thicknesses and types

THE BITS OF AN FDM PRINTER

HERE WE SHOW YOU THE MAIN PARTS OF AN FDM PRINTER. THESE ARE PRINTER SPECIFIC, BUT EACH MODEL SHARES SEVERAL COMMON ASPECTS

Filament will travel along this in tube in an unmelted state – melting doesn't happen until it get towards the nozzles. The material will be kept in a coil and unwound as the printer lays down the material it needs

The material is extruded from these nozzles, including both the support material and the main build material for your model. The nozzles will move around on the X and Y axes to complete the layer and will move up to start a new one

This is the bed on which the parts are made. It can be heated or coated in some way to stop models sticking to it. This bed is normally stationary while the nozzle moves about

Sometimes a cover is placed around the outside of the printer to keep heat in and make the prints more stable

WHY CHOOSE AN FDM PRINTER?

KNOW THE GOOD AND THE BAD OF FDM PRINTERS

There are a lot of benefits to having an FDM printer. For starters, a lot of the companies have made their printers open source, so there is a vast range of modifications, tips and people out there that can help you out if you get stuck with something. Materials are also cheap in terms of 3D printing – reels of ABS filament are around the £30-40 mark depending on the quality and brand you go for. The variety of materials to choose from also means that there will be something to keep everyone entertained.

SINGLE VISION

One other benefit of FDM printers is that they are quick to do their thing because they only make one model at a time. This means that if you've finished your first prototype in the morning, you could set your printer to run over lunch and come back to find your part done or pretty near completion. Plus they're awesome to watch!

THINGS TO BE AWARE OF

Of course there are downsides to using one. Because of the layer-by-layer process, you do get some fairly obvious lines across the whole model. This may not be a problem for an initial prototype or for something to show your friends, but it isn't great if you need to present to a client or investor.

The models can also be weak (this depends on the material used), and again the layer-by-layer process is to blame. It's like placing Lego on top of each other; strong if you push it from the top, but weaker if you come at it from the sides. It's also not the best form of printing if you're looking to do a small production run, as consistency between batches can be a problem, but mainly it is due to the time it takes to make a hundred of them when it can only print a single model at a time.

PROS

- Quick
- Lots of different types of materials can be used
- Open source software

CONS

- Not very accurate
- Layer lines are evident
- Slow to turn around large quantities of items

The way that SLS prints are fused together during the printing process means that you don't get layer lines

SLS printers are pretty industrial machines and not really the sort of thing that you'd use at home

If you have small, delicate parts to print then SLS might be best

SLS is also suitable for models where a high level of accuracy is required

THE EXPENSIVE, INDUSTRIAL PRINTER

SLS PRINTERS CAN COST OVER £250,000, ARE SEVEN FEET TALL AND RUN AT ROUGHLY 150 DEGREES

SLS (Selective Laser Sintering) printers are not exactly user-friendly. These machines are usually run by bureaus, with people buying their models from the company rather than buying the printers. The process of SLS is quite different to FDM machines – SLS machines normally use a nylon powder which is put down as an entire layer rather than just where it is needed. This bed is heated constantly at around 150 degrees centigrade. The laser above the bed of powder then maps out the CAD data with an accuracy of 0.1 mm. The laser actually spikes the nylon powder over its melting point of 170 degrees and melts the top layer into the ones beneath it. This fuses the layers together and creates a very strong bond, meaning the parts are extremely durable.

After the machine has finished its full print, which can take up to 30 hours depending on the number of parts and the complexity of the design, the entire print bed then has to be transported to a breakdown station and each model is removed from the unsintered powder. The powder that can be removed is then actually recycled and mixed with fresh new powder and put back into the machine. As some powder gets stuck to the outside surfaces of the parts, it then needs to be removed with a stiff bristled brush, before the more stubborn powder in recesses is removed with compressed air. All of this equipment costs thousands of pounds to obtain and each process basically needs its own room, as the amount of dust that gets airborne is crazy.

HOW CAN I USE SLS PRINTERS?

After reading the above, you can see why SLS printers aren't available as desktop models for home use. Instead of buying the machines, people will send their CAD data in STL format to the companies that own them, and effectively rent out the space in their printer. This means that people have access to these highly accurate printers without having to fork out the money to buy one.

You can easily order SLS prints online from places like Shapeways and Digits2Widgets

THE SLS PRINTING PROCESS

READ ON AND DISCOVER IF AN SLS MACHINE IS THE SOLUTION TO YOUR PRINTING NEEDS

SLS printing will get you a superior surface finish and a high level of accuracy. SLS machines will normally run around a 0.1 mm layer resolution and the melting process means that the layer lines on the prints are hardly noticeable as each layer blends with the one beneath. The printer is much more accurate in terms of tolerances too – parts that are produced are normally accurate to the CAD file within 0.1 mm. This means it is very similar to the tolerances that can be found from a part that is mass produced from a method like silicone injection. Many people use SLS printing to test their designs before they go into production.

INSTANT RESULTS

SLS is also able to produce parts that work straight off the printer due to the self-supporting nature of the nylon bed. This means you do not need support material, and you can create live hinges, wheels that are already attached to models, plus working mechanisms that don't have a giant gap between them. SLS printers are also able to print more than one thing at a time. Again, because of the self-supporting nature of this technology you can build anywhere in the available 3D space, allowing you to run upwards of 200 parts within the same build and meaning small production runs can be completed on the same print.

THE PAYOFF

This technology does come with its limitations. It normally takes at least 48 hours for a full print to complete (24 hours to print and another 24 to allow the build to cool down). The materials are expensive but this is countered by having a company do the printing for you. Yet part of the fun of 3D printing is watching a model being made in front of you, and with SLS this is not possible.

PROS

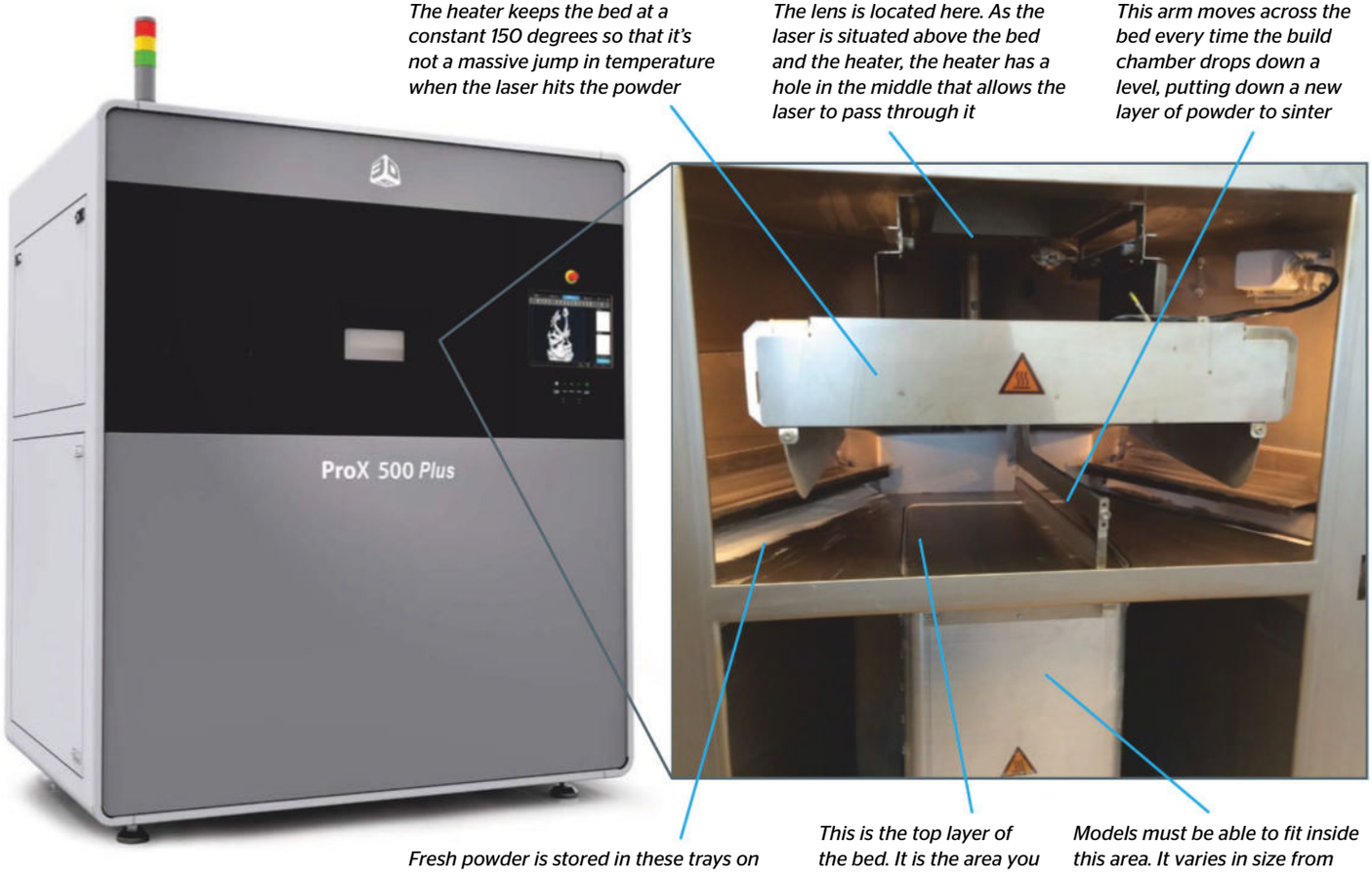
- Very good surface finish
- Very accurate parts are produced
- Parts are incredibly strong

CONS

- Slow to produce items, prints take days to finish
- Machines cost £250,000, so a bureau is needed
- Only comes in a single colour

A VIEW INSIDE AN SLS PRINTER

THE OUTSIDE OF AN SLS MACHINE IS PRETTY BORING – IT'S THE INNER WORKINGS THAT ARE MAGIC



The heater keeps the bed at a constant 150 degrees so that it's not a massive jump in temperature when the laser hits the powder

The lens is located here. As the laser is situated above the bed and the heater, the heater has a hole in the middle that allows the laser to pass through it

This arm moves across the bed every time the build chamber drops down a level, putting down a new layer of powder to sinter

Fresh powder is stored in these trays on either side of the printer. The blade spins a plate as it comes across that puts more powder in front of it for the best pass

This is the top layer of the bed. It is the area you can see and the area that the laser hits to sketch out the CAD file

Models must be able to fit inside this area. It varies in size from machine to machine, but all the parts are contained in here along with the unsintered powder

THE RESIN-BASED DETAIL PRINTERS

SLA AND DLP PRINTERS BOTH USE RESIN TO MAKE THEIR PARTS, BUT DIFFER SLIGHTLY IN THEIR METHODS

Stereolithography (SLA) and Digital Light Projection (DLP) printers are both similar in that they use a liquid resin to make their parts. Because they make their parts from a liquid, you are able to get a significantly finer print and can get some parts that go down to incredibly fine details – some so fine that you would need a microscope to fully appreciate them. They actually print by shining UV light at the resin for long enough to turn harden, in what is called the curing stage. The cured resin is sometimes still a little soft depending on how long it was exposed to UV light while in the printer, and shorter print times can affect rigidity. Because UV light is all around us, the models can be left to harden in the sun, or they may be put under a special UV light in order to quicken the process.

As you can imagine, the liquid is not self-supporting like powder-based printers, so in a similar way to FDM, both SLA and DLP printers will add a support structure to the overhanging parts automatically in a sort of scaffold layout. This support is made from the same resin and hardened in the same way, meaning that it needs to be picked or cut away by hand first, in order to clean the model up before the refining and polishing process can begin.

"Because they make their parts from a liquid, you are able to get a significantly finer print, with some incredibly detailed parts"

SLA PRINTERS

SLA printers vary – some build upside-down and pull parts out of the resin at an angle, while others drop the bed in the pre-set layer increments. A layer of support material is normally put down first to enable the part to be removed without being damaged. Layer levels on this type of printer can range from 0.15 mm all the way down to 0.05 mm, producing some incredibly accurate and finely detailed parts with almost no visible layer lines. The bed moves after each pass of the laser, and if the printer builds traditionally then an arm may come across to put down fresh resin. Otherwise, as the bed rises, resin floods into the position of the previous layer. Some SLA printers build on a 45-degree angle, as they require a peeling motion to stop parts from sticking to the bottom of the tank. It also reduces the duration of laser bursts, reducing excess curing and enabling more resin to be re-used.

DLP PRINTERS

DLP printers build the model upside-down while suspending it above the bottom of the tank of resin. After each projected image is shown, the bed moves up to allow a new layer to be created. Again, support material may be necessary to support any overhangs in the design. The projector underneath the model projects an image of the entire layer at the resin for around eight to ten seconds to cure it. The layer time is of course machine dependant, as well as dependant on the strength of the projector itself. This makes it a much faster process than SLA, as it skips the step of re-coating the print bed and having to draw and colour in the CAD file. DLP also allows you to print multiple items on the same print bed at the same time. Again, this is due to the process of image projection rather than having to draw a cross section across the whole bed with a laser.

This is the B9Creator, a 3D printer that uses a DLP projector to cure a photopolymer resin

This is the printer's Arduino shield, which handles all of the motors

The B9Creator uses a modified D912HD projector

SLA PRINTER *NOT ALL SLA PRINTERS ARE SIMILAR, BUT THEY SHARE SOME KEY PARTS*

It might look funky, but the orange casing actually filters out the blue light that cures the resin. Without it, you'd end up with a semi-solid chunk of resin at the end of your print

The bed on which the part is built works upside-down and is pulling the part from the resin in this image

This is the support material that is used to keep the part off the bed and allows overhanging parts to be built

This container is where the resin is stored before it is cured

The laser on this particular printer is located underneath and fires upwards into the resin to cure each layer

HOW RESIN-BASED PRINTERS WORK

GET FAMILIAR WITH THE MECHANICS

Both types of machine are quick to produce single parts – some things can take under an hour to produce. They can also capture incredibly fine detail, and can go down to a feature size of 0.3 mm, which is much more than you can get from other printers. Due to SLA and DLP using resin as their material, you are able to get a part made from a transparent or translucent material that has minimal layer lines. You can also buy SLA printers for use at home, meaning that if high detail is what you're after with your prints, rather than functionality (ie if you're a character modeller or if your parts will very rarely be handled) then this would be the better option for you.

MONEY MATTERS

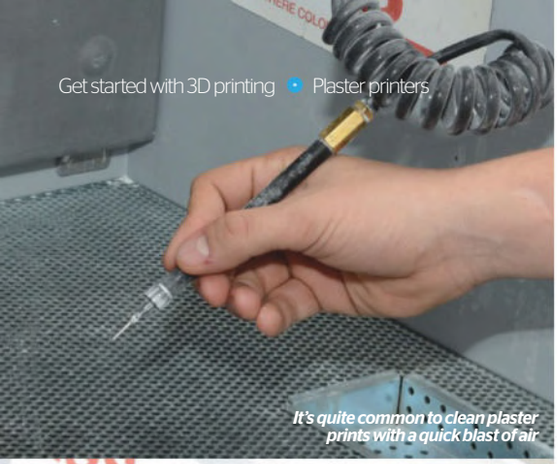
The biggest problem is that resin is expensive, however because it is re-usable you don't lose your entire build volume's worth every time. Both printers do require support material that needs to be removed post-process, either by picking it off by hand or by dipping parts into a chemical bath to remove the trickier stuff. This means complex parts or parts that are designed to be moving do require a larger tolerance so that you can remove the support. Lasers and the projectors themselves can be expensive to replace when they go wrong, and while this isn't frequent, the service costs should be taken into consideration.

PROS

- Can capture very fine detail
- Layers are very small so overall surface finish is much improved
- Can produce parts very quickly

CONS

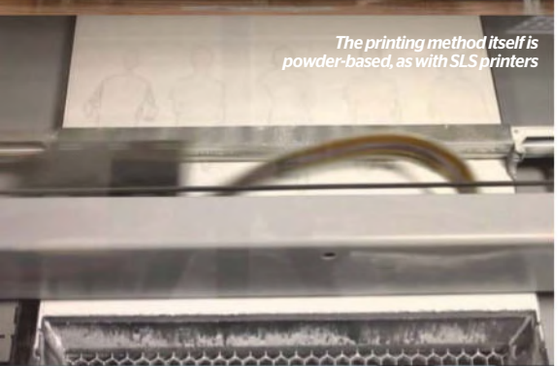
- Expensive machines, servicing is also expensive
- Support material is used that needs to be removed with chemicals
- Resin is also expensive to buy



It's quite common to clean plaster prints with a quick blast of air

These are pre-prepared cartridges, ready to be mixed together during the printing process

Plaster printers are usually quite large, like this one down at the iMakr studio in London



The printing method itself is powder-based, as with SLS printers

Many plaster printers will include a suction duster, to help remove the unused powder

THE COLOURFUL, AFFORDABLE PRINTER

THIS PROCESS USES A PLASTER POWDER AND A BINDING AGENT, AND ENABLES USERS TO PRINT IN FULL COLOUR

Plaster printers use a plaster powder which is covered with a binding agent, normally water, in order to create the solid object. They use the same technology as a normal 2D colour printer to draw out each layer in turn, and in some cases the printer uses a very similar nozzle to the ones found in your desktop printer at home, as they are able to print on a flat plane in full colour. As plaster printers are powder-based, like SLS printers, the parts are self-supported and therefore you are able to make significantly more complicated shapes with them. A dye is also added through the binding agent, which allows the printer to make parts in full colour. For a while this was the only way that you could 3D print in full colour, however companies are now offering full colour plastics. Regardless, this is not yet as established as plaster printing and so plaster still remains the most popular and cheapest way to produce 3D colour prints. This is primarily because the powder itself is relatively inexpensive compared to other materials, as is the binding agent. Plaster printers are normally what will be used to print the 3D 'mini me' models that have become extremely popular recently, as their ability to capture colour it makes them the perfect printer for the job. However, plaster printers can struggle to print skin tones and they can have difficulty when trying to match certain shades of colour, as they are trying to create everything from a limited availability of dyes. Finally, due to their somewhat fragile construction, it should be noted that plaster prints should be considered as visual pieces only, rather than as working components.

WHAT PLASTER IS USED FOR

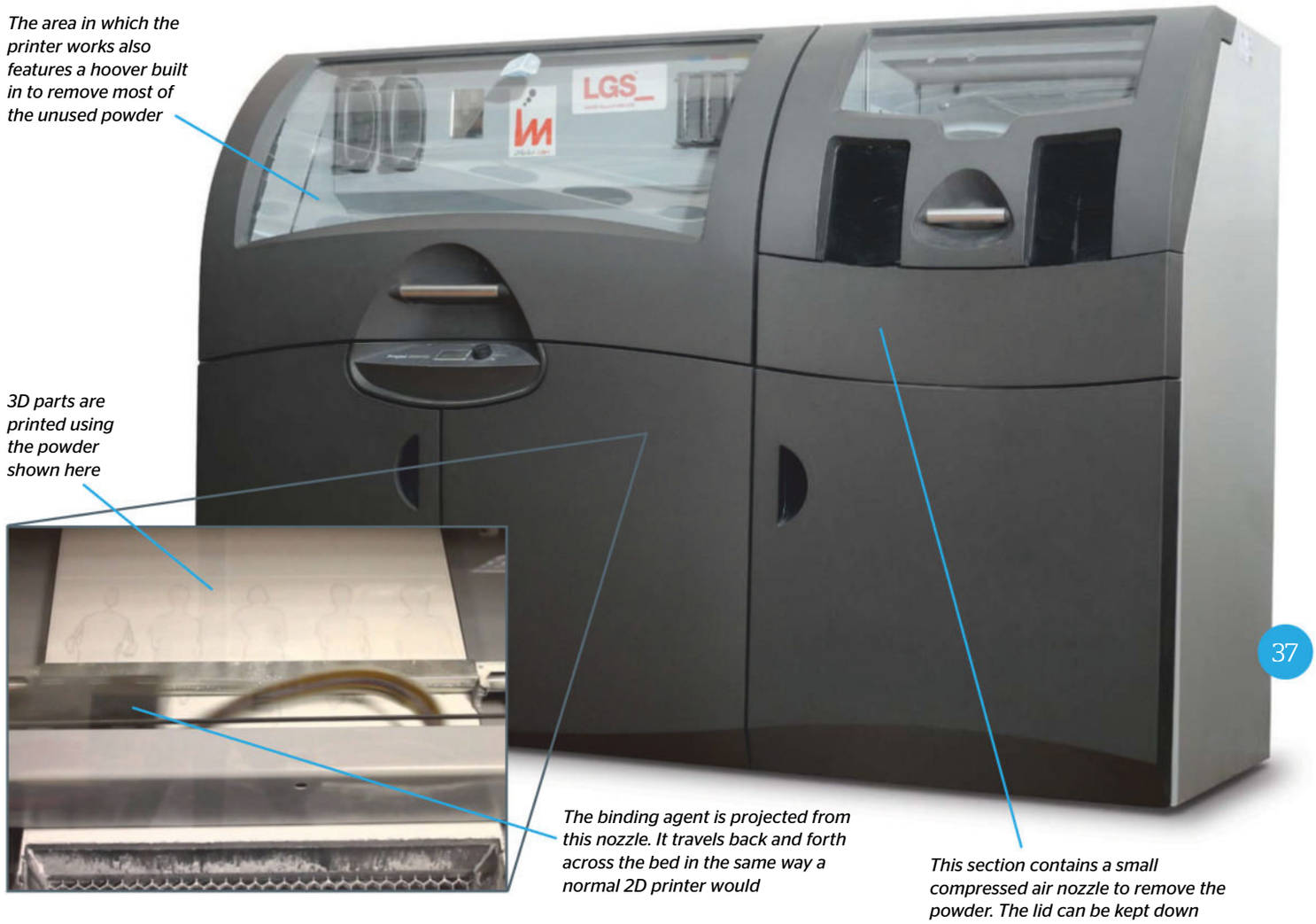
Because of the delicate and fragile nature of plaster-based prints, they do have a very limited application. Most companies will recommend that powder printers are kept to just visual pieces, such as architectural displays, fine art or museum exhibitions, character modelling and also for educational purposes. Plaster printing has the benefits of being cheap and quick, with some companies offering same-day services on specific parts. The simple (compared to other forms of 3D printing) technology also means that the costs are kept to a minimum.

Colour is unrivalled with plaster printing methods

While skin tones aren't perfect, they're still great

A LOOK AT A PLASTER 3D PRINTER

THIS PROJET 660PRO IS A FULL COLOUR PLASTER PRINTER. HERE'S A BREAKDOWN OF THE MAJOR COMPONENTS THAT GO INTO MAKING IT



MAKE VIBRANT 3D PRINTS

DISCOVER THE UNIQUE PROPERTIES OF PLASTER PRINTERS

Plaster printers introduce colours by adding a dye through the ink jet nozzle at the same time as the water is binding the plaster together, or on some printers four different preset coloured glues combine together to achieve the closest match to the colour on the CAD file. The process is also powder-based and the layer is reset by an arm that re-coats the bed with a fresh layer of powder in 0.1 mm layer increments. An ink jet head is then passed over the top to colour in the layer. This part is very similar to a standard 2D printer as it uses the same sort of nozzle technology.

KEEPING IT ALL TOGETHER

Plaster printers produce parts that have a grainy texture when removed from the machine, and which, depending on the treatment, can be very brittle. In some cases a UV coating is sprayed over the top to stop the colours fading in the sunlight, but to stop the prints from breaking apart in your hand the part must be dipped in superglue, or a wax coating must be applied. These seep into and bind to the material to make it much stronger.

THE CLEAN-UP PROCESS

As with all powder-based printers, the powder is self-supporting so there is no need for support material. However, there has to be some way of removing the powder from around the print without handling it in its most delicate form. Most plaster printers will have some form of vacuum that removes the powder and recycles it back into the machine to be used in subsequent prints. This may not remove all of the powder, though, so a fine air blaster may also be necessary.

PROS

- Full colour
- Can produce parts same day
- Great visual impact

CONS

- Parts are delicate until treated
- Colour can fade over time unless coated for protection
- Will likely require a bureau as it's a messy process

UNDERSTANDING FILAMENTS

FILAMENTS ARE WHAT YOUR 3D PRINTS WILL BE CREATED WITH ON YOUR DESKTOP PRINTER. FIND OUT WHICH IS THE BEST FOR YOU AND YOUR PROJECT

PLASTICS

You've done the hard part and decided which 3D printer you'd like to try. The next step is buying the requisite materials for printing, the first being filaments. The most common varieties of 3D printing filament are plastics, typically PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene), and these are both widely and cheaply available on the internet or from specialist stores.

There are distinct differences between them, mostly rooted in their strength, precision and melting point. You can also choose from a wide variety of colours to add that little bit more character to your prints, and can even print in multiple colours if your object is separated into different parts and assembled later. There are dual-extrusion machines out there that allow you to print in two colours simultaneously, but they're not that common as of yet.

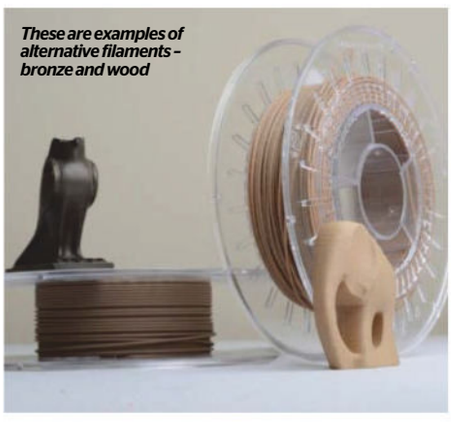
There is more information on ABS and PLA on the opposite page and they're both readily available. You'll be surprised by how cheap a ream is – 3D printing can be more cost effective than using an inkjet printer!

ALTERNATIVES

As well as common plastics, there are a few less orthodox alternatives in the filament market. There are filaments that are still mostly plastic but contain particles from other areas. Wood is a good example – try telling someone that you can print wood and check out the look on their face! More practical and widely used, though, are carbon fibre and metal filaments. Carbon fibre filaments in particular are used by several car companies to print smaller, internal parts of vehicles, and recently a company printed the entire chassis of a Shelby Cobra using the stuff.

What is considered the next big step in filament production is conductive filaments. It won't be long before you'll be able to print conductive materials, allowing you to essentially print internal electronics.

Whatever you choose, keep an eye out for all of the options as there are more and more varieties of filament appearing on the market every day.



These are examples of alternative filaments – bronze and wood

There are some filaments out there that have a basis in more malleable materials

PLA

INTRICATE, CLEAN PRINTS

Although it might not seem like the most important facet of deciding which filament you'd like to use, it's worth mentioning that PLA smells a lot better during extrusion. While we'd always recommend that you 3D print in a well ventilated environment, it's certainly more important with ABS than its pleasant-enough smelling cousin.

PLA is a polymer that melts at a relatively low temperature, only needing to achieve around 60 degrees Celsius before it starts to become malleable. This does limit its uses somewhat, as allowing an object printed in PLA near anything of that sort of temperature will likely turn it into a gooey mess pretty quickly.

One of the key things to consider when it comes to PLA is the fact that it is biodegradable and compostable – peace of mind if you're concerned about the impact of your printing on our environment. It is also resistant to water, so is pretty handy for outdoor objects. It's more brittle than other alternatives, though, so it's worth considering carefully what you'll be printing before doing so. Although, you could happily print a detailed, delicate item in PLA – it's less prone to warping than its heftier opposite number – you wouldn't want to be printing anything that is likely to be dropped.

As aforementioned, though, you need look no further if you're in the market for creating something intricate and decorative. Just try to keep it cool...

PLA is a better filament for achieving detail in your prints, although it is quite weak

ABS

ROBUST, HIGH MELTING POINT

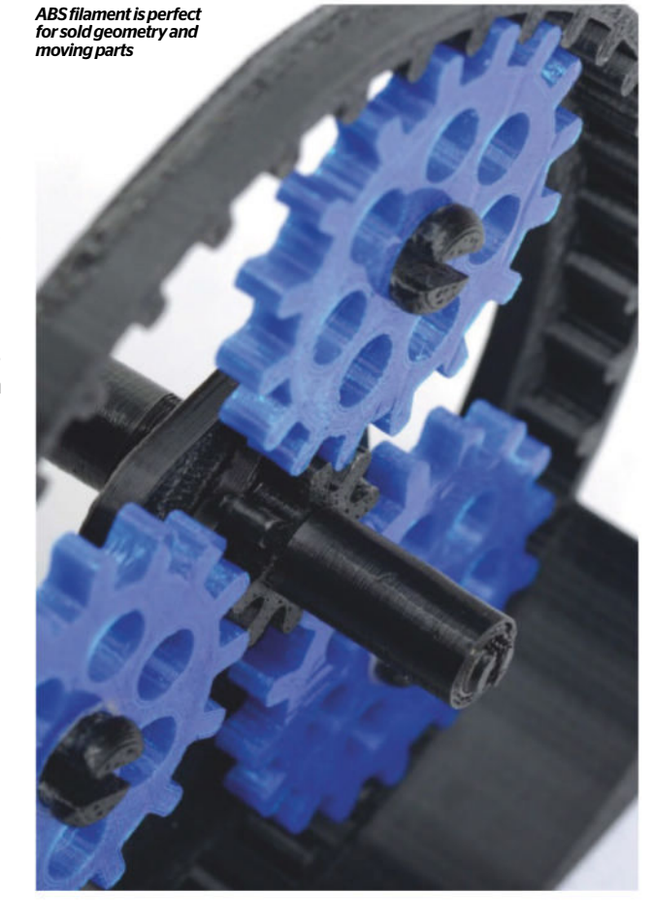
ABS is the other popular filament on the market. It lacks the detail and stability of its main counterpart when used with certain printers but more than makes up for this with its higher melting point and stronger constitution. You need not worry about leaving this stuff out in the sun – ABS doesn't begin to soften until it reaches beyond 90 degrees Celsius.

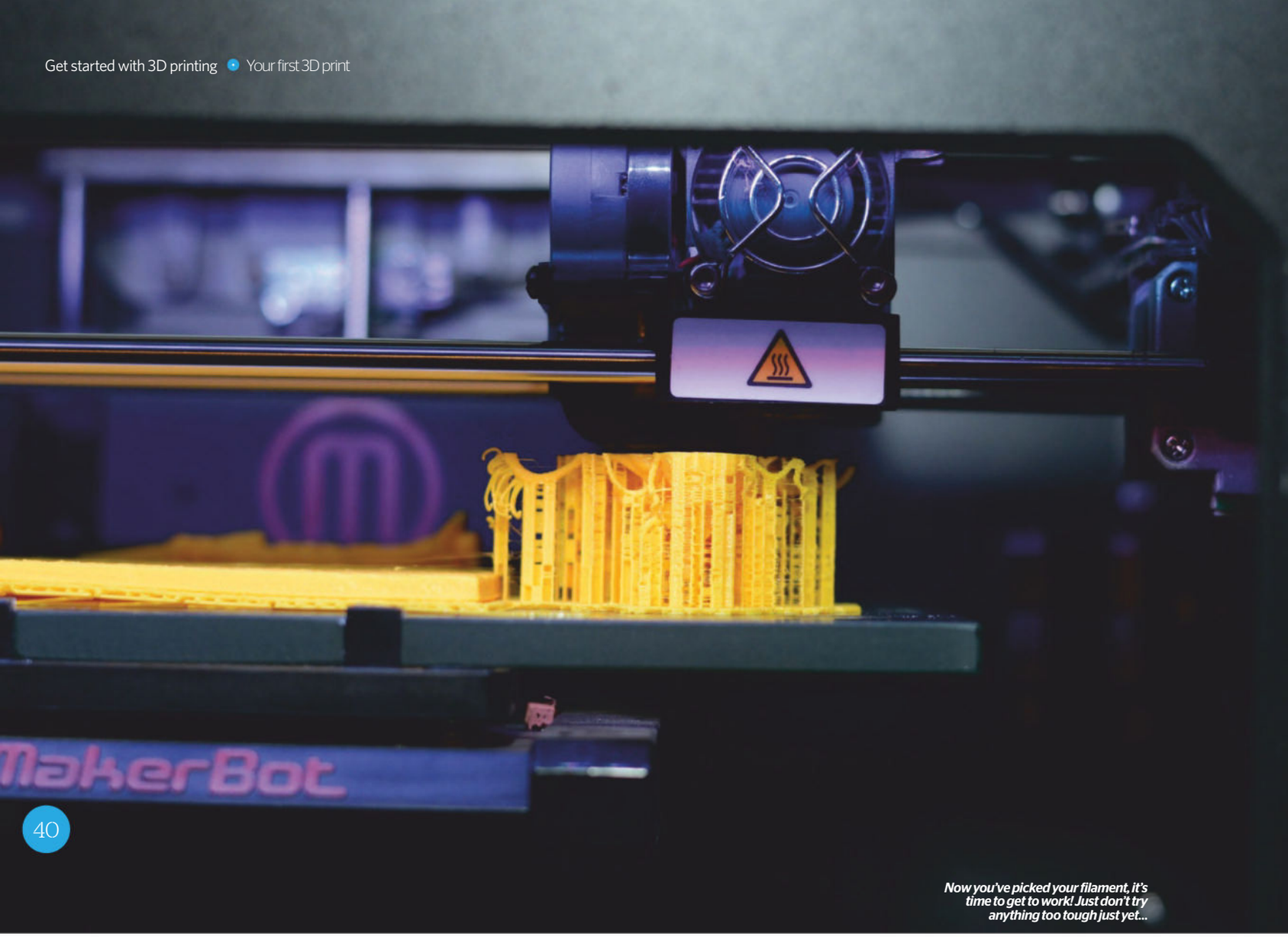
It's important to understand that just because we've told you that ABS is a bit stronger than PLA doesn't mean that it's totally invulnerable. Everything rests with the initial 3D design of whatever you're endeavouring to make (more on which later), and we don't see the need to hammer home the fact that you're making things using plastic – it's still a long way from steel, so don't go chucking your designs around. Still, ABS, when printed in proper layers, is more liable to bend than snap under pressure, unlike PLA.

The operative line here, though, is: it's strong but it smells. Unfortunately, during extrusion from a 3D printer ABS gives off a rather foul smell – it's obviously not a deal breaker but it's worth bearing in mind. It also isn't biodegradable like its more environmentally friendly rival, which is worth considering before you invest.

Whatever happens, if you're looking to print something solid with a high melting point, ABS is definitely the way to go. This makes if perfect for things around the home, whether it be ornaments, utensils, toys or otherwise.

ABS filament is perfect for sold geometry and moving parts





Now you've picked your filament, it's time to get to work! Just don't try anything too tough just yet...

YOUR FIRST 3D PRINT

GETTING STARTED WITH 3D PRINTING DOES NOT NEED TO BE A DAUNTING TASK, MAKE A START TODAY

Don't be too ambitious for your first print. Start with something simple as this will help you understand your particular printer, as well as identify if there are any problems. If you have built your printer yourself this is particularly important as there are many things that need to be calibrated.

Once your prints look the way you want them to (you can download calibration prints to use as a benchmark), you can then move on to more complicated designs.

You need to crawl before you can walk, though, so don't jump into something massively complicated straight away. Build up gradually – this way you will get to know your particular printer and what it is capable of. After you are satisfied with the quality of your first few prints, try printing something with a few different parts that fit together. This will allow you to see that your machine is printing accurately enough to deal with tolerances, tight fits and potentially moving parts further down the line.

"You need to crawl before you can walk so don't jump into something complicated. Build up gradually – this way you will get to know your particular printer"

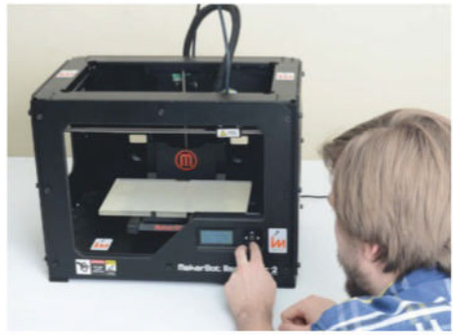
Next, go for something big and complicated, maybe with many parts that snap together, or something that incorporates moving parts straight from the print bed. This will be a good test and help build your confidence.

Lastly you can start experimenting with different materials. First make sure that your printer can take 'exotic' materials such as flexible filament, and then start experimenting with different layer heights, melting temperatures and print speeds.

The more you play the more you will learn. Always research before trying something new, and once you are confident, work with a variety of settings, prints and materials and really get to know your printer.

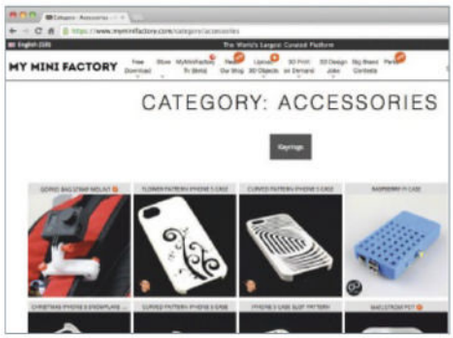
01 UNBOX THE PRINTER

First you will need to remove your printer from its box and plug it in. Usually the manual will be placed so it is accessible as you open the box – use it as a guide for unpacking as a printer can be quite fragile. Remember how it was packed in case you need to repack it!



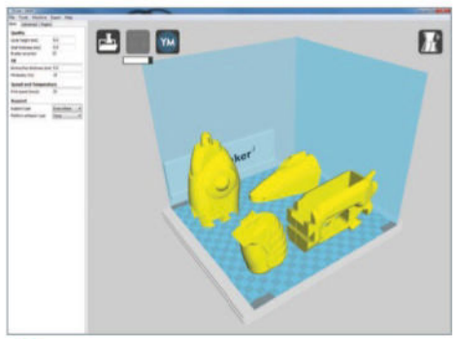
02 SET UP AND CALIBRATE

At this point, different varieties of printers will differ quite a lot in their setup and calibration. The best course of action at this stage is to familiarise yourself with the instruction manual. This way you will be sure you are employing the best practices for your particular machine.



03 DOWNLOAD A 3D MODEL

To start printing, you will need a 3D model. Head over to **www.myminifactory.com** and choose something simple. Look at images of the final print to see what it should look like once printed. Choose something that won't take long to print, this way you will quickly be able to see that your printer is operating.

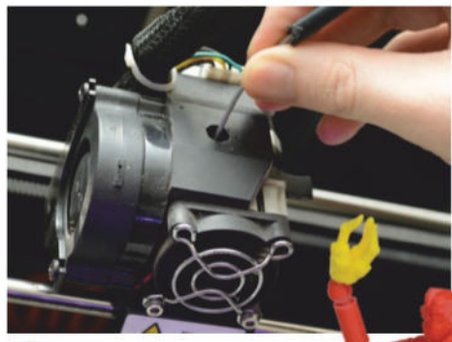


04 IMPORT TO SLICER

Next you will need to slice your model. Install your printer's slicer from the disc provided, or from the manufacturer's website. Different printers use different slicers, so make sure you use the right one! In your slicer, select File>Import and select the STL file that you have downloaded.

05 FROM PC TO PRINTER

Scale your model and choose your settings. Here you will decide on the size of your model, as well as the print resolution, infill and other settings. Hit Slice. After your model is sliced (this could take a few minutes) save the sliced file to the external storage that your printer uses. Insert this into your printer.

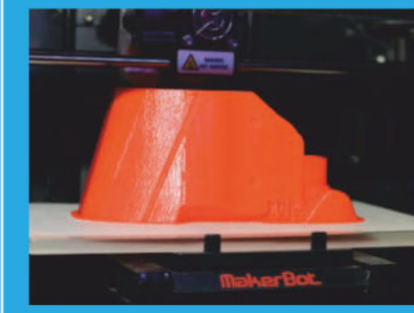


06 LOAD AND PRINT

Choose a filament, select the Load Filament option from the menu and follow the instructions. Once your filament is loaded, select 'Print from storage device' (or similar) and select the design you have sliced. Hit Print and off you go!

BEFORE YOU START

You're almost there, but here are some reminders



01 LEVEL BED

In order for your printed object to be level, the print bed of your printer needs to be level as well. Options for checking this can be found in your printer's Settings menu, usually found by navigating its LCD screen.

02 CHECK FILAMENT

Now it's time to make sure that you've installed your filament correctly and that the variety that you have put in your machine is what you want to be printing. Have one last think about what it is you're printing and how suitable your filament actually is.

03 CHECK 3D MODEL

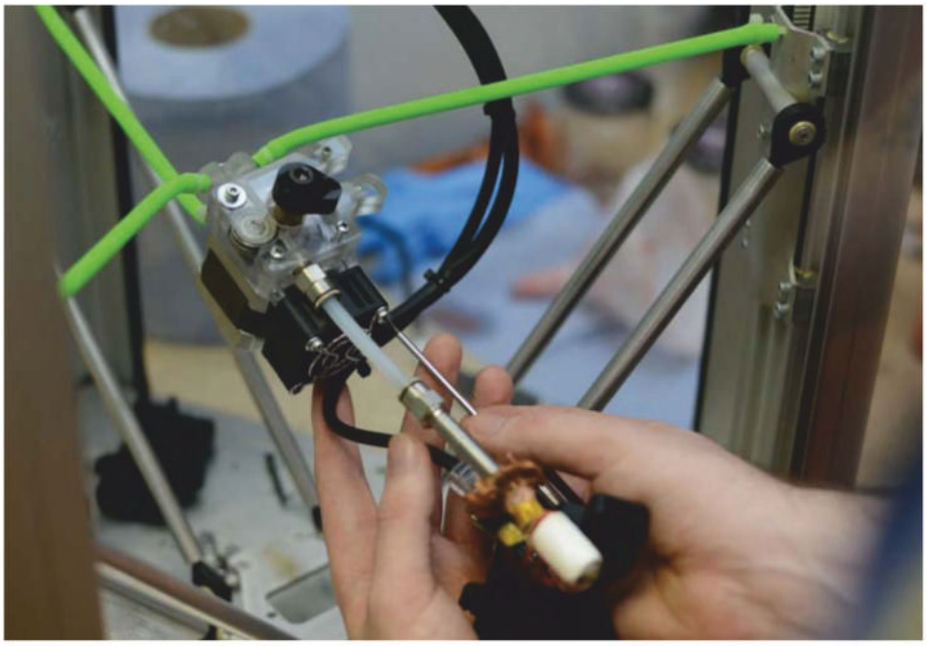
Double check your 3D model before you hit print. Ensure it is suitable for printing, keeping an eye out for areas of potential overhang or weakness that might ruin your print later on. Once you're certain it's the right model for you, check it has been sliced properly and then import to your printer.

04 CHECK TIMINGS

Timings for any particular print will vary massively between different models and different printers, so keep an eye on how long your print is actually going to take (there should be a timer on your machine's LCD screen). It's important to realise how long you'll have to leave the machine running for when printing large or intricate objects.

05 SAFETY FIRST

You're using a piece of machinery that melts plastic in seconds, so care is advised. Make sure the room is well ventilated and keep fingers away from the nozzle!



MAINTAINING YOUR 3D PRINTER

LEARN HOW TO FIX YOUR PRINTING IF AND WHEN SOMETHING GOES WRONG

FILAMENT MAINTENANCE

There are a few essential things to keep in mind when handling and storing your filament. Make sure that once you have opened your filament, you store it somewhere cool, dry and free of dust. The printer's extruder is very sensitive and as such even small bits of dust can lead to clogging. Dust will accumulate on your filament over time if it is left in the open. Prevent this by keeping it covered.

Filament can also become twisted if not cared for properly. Make sure that when you are loading and unloading a spool of filament that you are very careful not to let it unwrap and start tangling. This can lead to a lot of wasted filament.

UNDER EXTRUDING OR NOT EXTRUDING AT ALL

Generally these are the most common problems you'll run into. An extruder that is not extruding properly will leave you with poor prints, while one that is not extruding will leave you with nothing!

It can be difficult to spot this at first, but generally when your print is about 1cm high you will see a type of 'fluff' being printed – you will see this looks very different to your usual print. Stop the print when you see this, and then run the load and unload script for your filament, as the most common cause for this will be a clog in your extruder. Loading and unloading the filament will usually fix this, if not you might have to dismantle your extruder and unclog manually.

WARPING AND BED MAINTENANCE

Another problem you may run into is your prints not adhering properly to your printer's print bed. This happens for a number of reasons and is a more common problem with larger prints that cover the entire bed. There are a number of ways you can combat this issue. With some printers you can use a bit of glue and paste it straight onto the print bed. Other printers will require you to put masking tape down to cover the surface. After each print you can rub this tape with alcohol to remove any residue.

LEVELLING THE PRINT BED

It is crucial your print bed is level – here's how it's done

01 LEVELLING SCRIPT

You need to go to Settings from your printer's display and select Level Print Bed. The printer will then move the extruder to different points on the bed.

02 FIX PROBLEMS

If the bed is uneven your printer will provide instructions for levelling the bed. This will usually involve turning screws at different points on the bed.

03 TEST PRINT

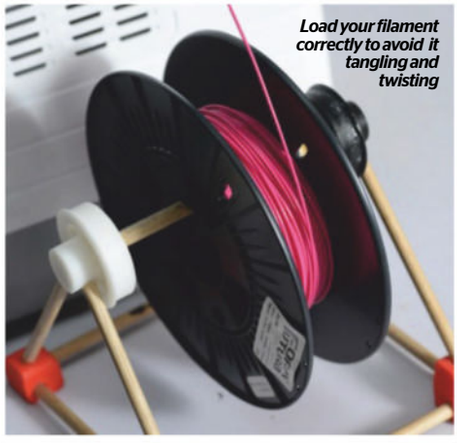
Choose a large flat design and set it to print. This will allow you to see that your printer is printing evenly across the entire print bed.

04 REPEAT

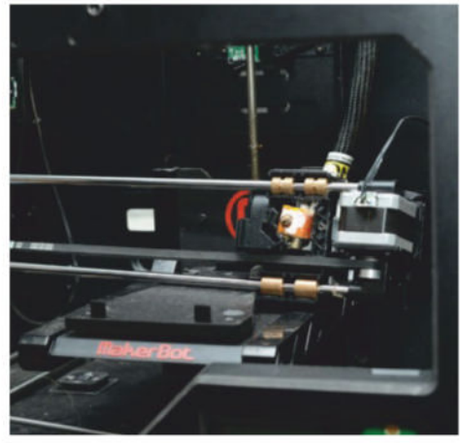
Now repeat the steps until your bed is level! As you do this more often you will get a feel for what needs to be done to level your particular print bed.

A failed print with clearly visible anomalies. There are many ways to correct this

A model moving on the print bed will result in shifting layers in your prints



Load your filament correctly to avoid it tangling and twisting



FAQ

MY FILAMENT HAS TANGLED – WHAT DO I DO?

Unload the filament, and slowly and carefully unwind it to the point where you find a knot, undo the knot, and then rewind the filament onto the spool.

WHAT ARE THE RIGHT PRINT SETTINGS FOR MY MATERIAL?

Use the preset profiles within your slicing software as a guide, familiarise yourself with your filaments and their properties by testing and experimenting!

HOW DO I REMOVE MY PRINT FROM THE BUILD PLATE?

Use a wallpaper scraper or craft blade to remove your sticky prints carefully from the build plate.

CAN I PRINT OBJECTS IN MORE THAN ONE COLOUR?

Yes. You can do this by printing your object in multiple parts and then gluing them together. You can also use a dual extrusion FDM printer which can print in multiple colours at the same time. Alternatively, you can just paint your prints!

HOW CAN I REMOVE SUPPORT MATERIAL PROPERLY?

After you have removed your print from the print bed, use a variety of tools to clean off the support material. Wire cutters are good for removing the large chunks, after which you can use a finer pair of pliers or tweezers. Use sandpaper after this if there are still rough edges that you want to smooth out.

CHECKLIST FOR BEFORE YOU PRINT

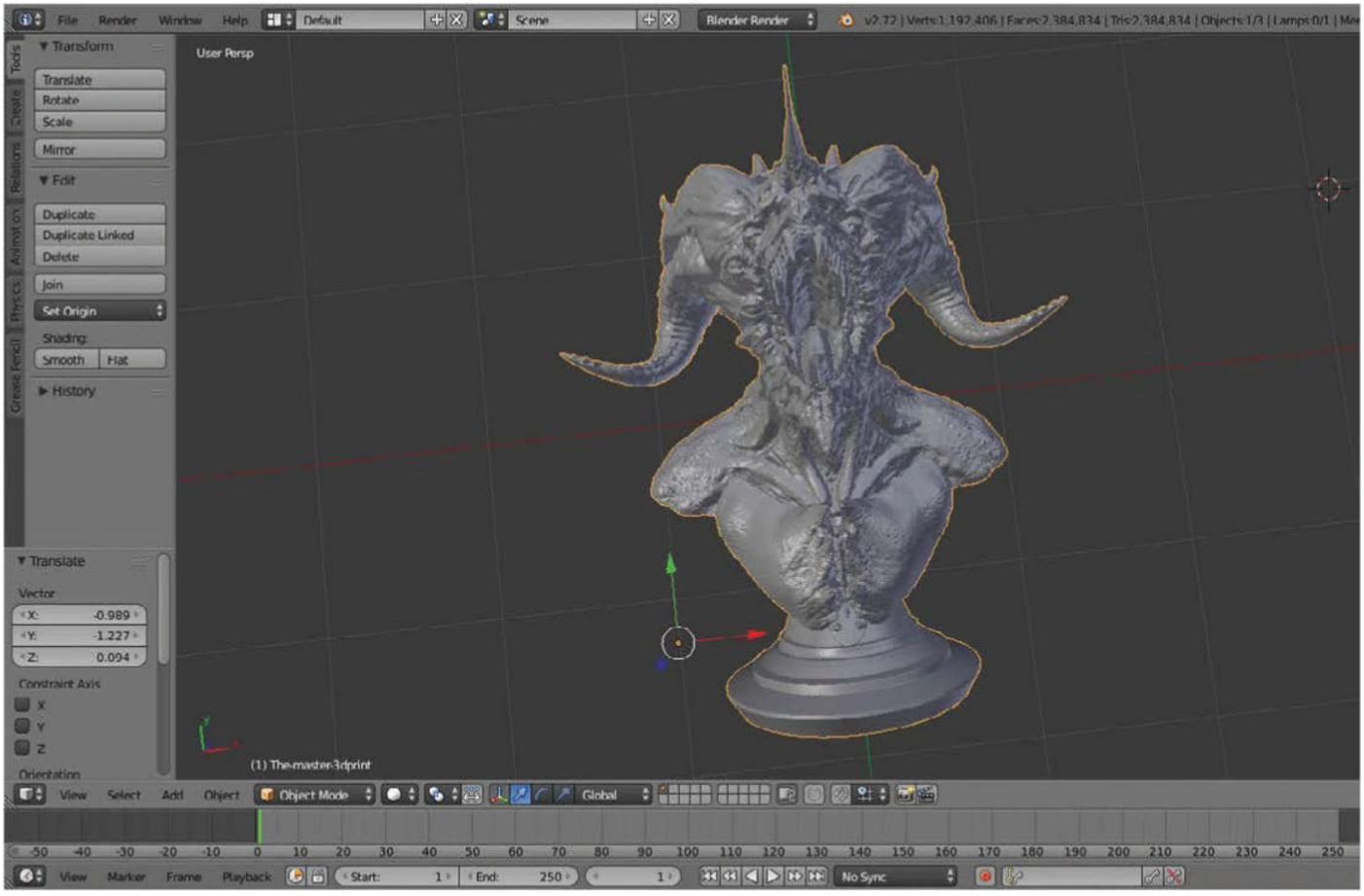
1) Is your bed level?
Check your bed is perfectly level; if it is not run through the steps that have already been outlined to level your print bed. Only move on once you are perfectly happy your printer and print bed are well calibrated.

2) Do you have enough filament?
Check that your filament is loaded (on its spool holder), is not tangled and that you have enough.

3) Is your 3D model sliced and on your external storage device?
Make sure that you have sliced your model with the settings that you desire, and then export it to your external storage device.

4) Is the slicer profile optimised for your printing material?
Different materials will require different print settings. Your slicing software will have different profiles that will contain settings ideal for different materials, so you need to make sure that you select the correct parameters for your printing material.

5) Is your extruder clean?
It's important to always check that your extruder and nozzle are clean and unblocked before you start printing – checking this every time without fail will ensure that your printer gets clogged far less frequently.



AN INTRODUCTION TO MODELLING

THERE ARE SEVERAL SOFTWARE PACKAGES THAT YOU CAN USE FOR MODELLING. DISCOVER WHICH ONE IS THE RIGHT ONE FOR YOU

Modelling a 3D object is the very first stage of what is called the 3D pipeline. You don't need to worry about this terminology too much, but essentially it is the stage that allows you to block out the object that you are designing, decide on its size and shape, and then add more intricate details before printing.

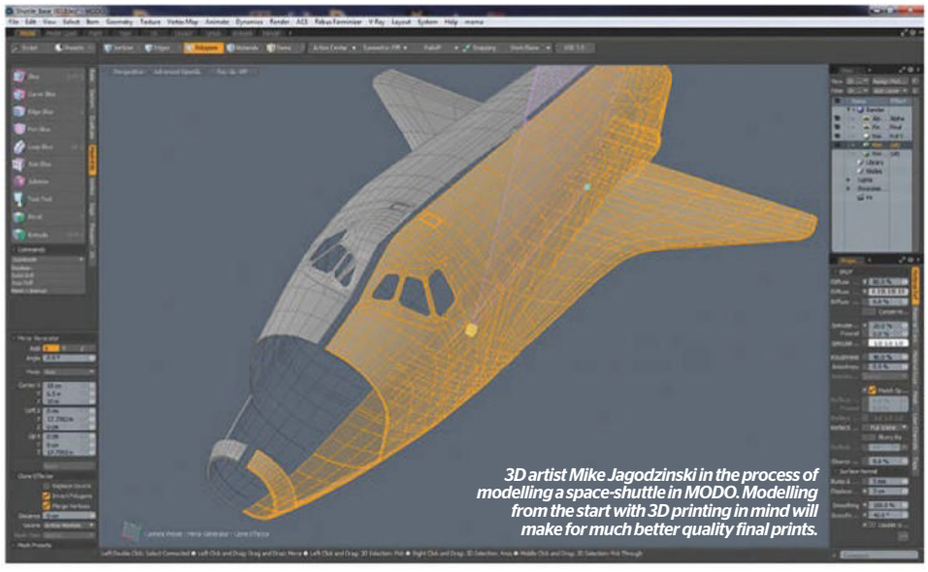
It's a crucial stage of 3D printing – after all, without a 3D model you certainly won't be getting a 3D print! It might sound a little complicated, but generally speaking it can be a very simple process. You're essentially playing with shapes on a computer screen and making sure they're suitable for printing, before exporting your geometry in a compatible file format.

Of course, it is vital that you choose the perfect 3D software to realise your printing visions – a model can demand a serious amount of time and effort on your part if it's quite technical, so you owe it to yourself to make the whole process as intuitive as possible. There are three different ways to create a 3D model; hard body modelling, surface modelling and digital sculpting, so picking a software package based on how you would like to model is a good way for you to start.

Hard body modelling is arguably the most basic technique here. You create your model by starting with a basic geometric block – like a cube – and then start adding material, taking away material and using it with other geometric shapes to build up the final effect.

Surface modelling is really quite similar to hard body modelling. Instead of creating solid bodies from standard geometric shapes, you individually generate all the surfaces of that same cube then join them together to make a solid cube. This gives

"Modelling is a crucial stage of preparing for 3D printing – after all, without a 3D model you certainly won't be getting a 3D print!"



3D artist Mike Jagodzinski in the process of modelling a space-shuttle in MODO. Modelling from the start with 3D printing in mind will make for much better quality final prints.

you the freedom to create far more intricate models with organic surfaces.

Digital sculpting is a process by which you sculpt and manipulate a block of material in a virtual environment. People who are from an art background are drawn to this type of software, because it is very similar to sculpting an actual block of clay.

COST PLAYS A PART

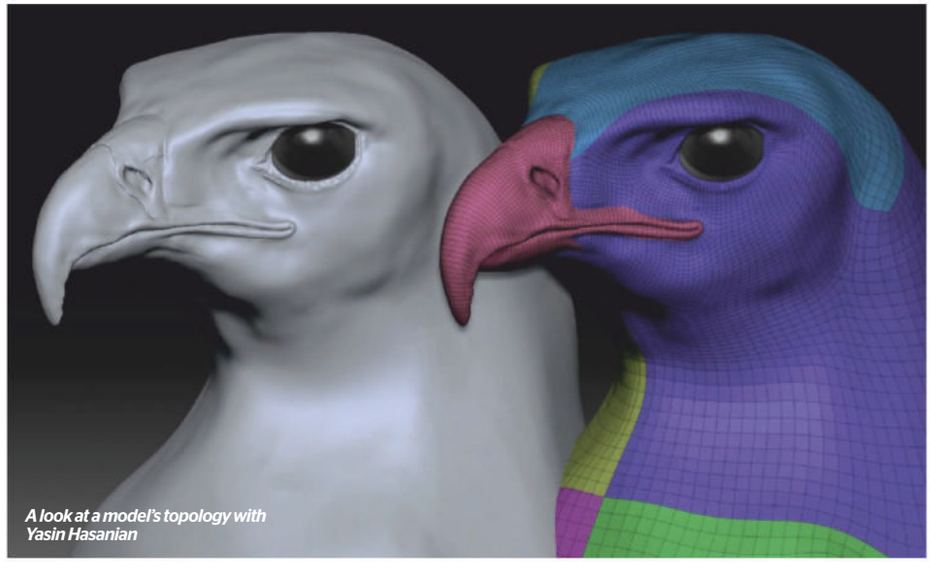
As is the case with other varieties of creative software, professional standard 3D software packages *can* cost you an arm and a leg. If you're only looking to experiment then a free software package like SketchUp will do the job, or you could download something a little more technical like Blender.

Basically, anything that can save models as an STL file is fine. Take a look online to see what's out there. If you're already pretty nifty when it comes to modelling, there are professional solutions such as ZBrush, 3ds Max or Maya that might be more useful to you, although they aren't cheap...

HELP IS AT HAND

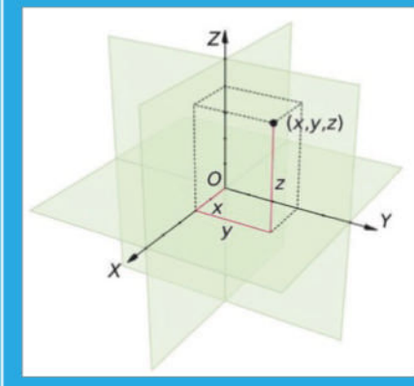
If you have no experience of 3D modelling, this can be the most daunting part of the whole process. However, nowadays there are websites and YouTube channels dedicated to tutorials for every 3D software package. Once you've decided what to use, hop online and see what sort of support is available.

However, you could always skip this part – there are a huge amount of free, good quality, 3D-printable models available on the internet from sites like **myminifactory.com**.



A look at a model's topology with Yasin Hasanian

CARTESIAN COORDINATE SYSTEM



Although any mention of coordinates may seem complicated, it's a key concept when it comes to 3D printing. A 3D object is measured in terms of its width, length and height – its x, y and z axes. These are in direct correlation with the corresponding axes that your 3D printer operates in, which is worth bearing in mind while modelling.

FILE FORMATS

In order to allow software to communicate with others – and your printer – you need to know which file formats are best...

STL
This format shows the surface geometry through structured triangles. As this is all coded into a binary file, the file is compact. This is usually the format you send to the 3D printers.

STEP
This is the most widely used data exchange form of 3D objects in CAD and 3D modelling. This is usually used to communicate between one CAD software and another.

OBJ
Also known as an object file. This format saves the object into a code which can only be read by a program that understands that language. This format tends to be used for high-poly objects.

FREE MODELS

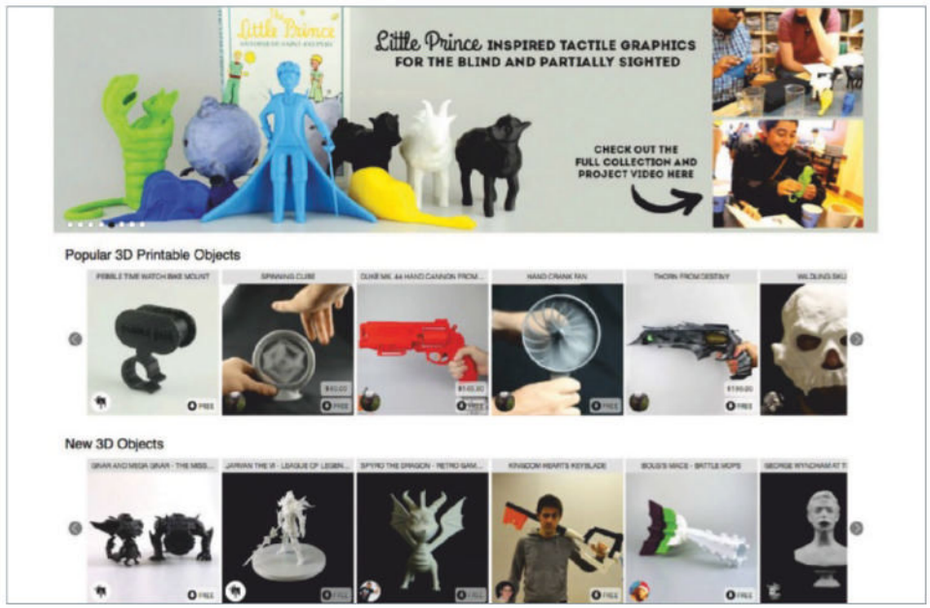
DISCOVER THE ONLINE OUTLETS THAT ALLOW YOU TO DOWNLOAD PRINTABLE MODELS FOR NOTHING

Free models for 3D printing are abundant nowadays and are offered by a large number of online retailers. Sites such as iMakr's MyMiniFactory, 3dprinter.net and TurboSquid offer a massive range, and even premium model sites such as CGTrader now offer a solid range of free, easy-to-download STL files for you to download and print at your leisure.

Now, we shouldn't have to tell you that the quality of free models on these websites varies quite a bit, but generally speaking you're extremely likely to find whatever you're after, whether it be household items and practical utensils to jewellery, figurines and ornaments.

It's quite hard to go wrong – simply visit the site of your choice, search for something you want and download the file. Always double check that the file is printable, but if you keep an eye out for STL files you can't go too far wrong.

The nice thing about downloading free models is that a vast proportion of them have been created by the community for other makers to use however they like. There's quite a large emphasis on open source hardware, software and assets in the 3D printing community, the idea being that you can create models and then share them easily across different platforms. The only thing you need to watch out for is the licence attached to each model, as there are certain restrictions on what you can and can't do with someone else's intellectual property.

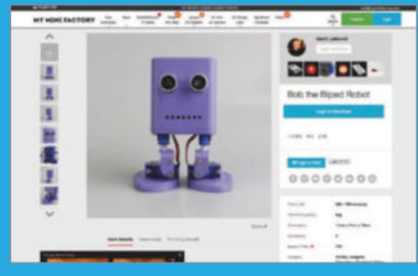


LEADING FROM THE FRONT – MYMINIFACTORY

MyMiniFactory, an online 3D printing marketplace affiliated with system reseller iMakr, is the world's largest curated platform for 3D printable objects. It offers an enormous range of files to download from a variety of categories, ranging from architectural models to props and accessories. It also boasts a thriving maker community that regularly contributes models to the site.

If you find yourself in the position that you've become rather adept at modelling for 3D printing, it would be worth your while to upload your designs to MyMiniFactory, as once they've been reviewed by the team of excellent designers that work there and test printed, they'll be placed on the marketplace for other users to download. You could even earn commission if your printed, assembled and cleaned model is sold as a premium product.

Additionally, if you have a particular 3D model in mind that you'd like to create but perhaps don't have the time or the skill to do so, the design team at MyMiniFactory will do the hard work for you, completing the modelling, printing and finessing your creation. It's a fantastic community – one that is very much the leader of the pack at present.

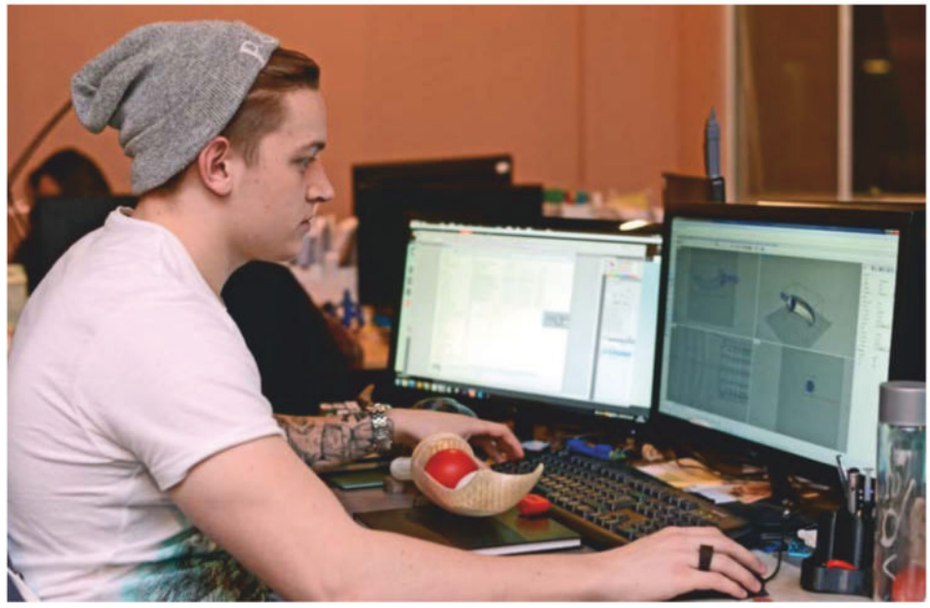


MAKE YOUR OWN

MOVE ON FROM USING OTHER PEOPLE'S DESIGNS AND START CREATING YOUR OWN 3D MODELS

While there's a huge amount of free models available online, and a massive community that continues to churn them out, you might want to consider actually making your own models for 3D printing. The prospect of doing so may put you off immediately, but 3D modelling can be an extremely rewarding process, and creating your own models will encourage you to join some of the fantastic maker networks out there where you can share your designs with other enthusiasts and receive feedback.

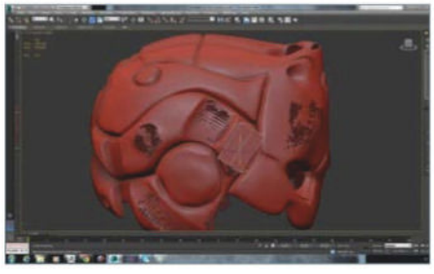
To create a 3D model you'll require some 3D software. This is another area where you are legitimately spoilt for choice, as there are hundreds of different applications available that allow you to create 3D models and export them in a file format that's suitable for 3D printing.



Some of them come at a rather hefty price, but generally the expensive software packages are the kind used by professionals or by VFX enthusiasts. It all depends on what you want to make. A premium software package like ZBrush or 3ds Max will proffer you more tools and more parameters to tweak, but if you're only looking to print a phone case then it's probably not worth forking out a pile of cash.

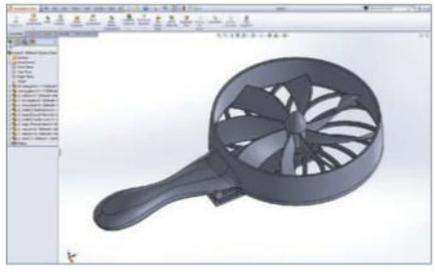
Fortunately, there are some excellent free alternatives for 3D modelling out there such as SketchUp and Blender that will prove to be more than adequate, without costing you a penny.

3D SOFTWARE *CHOOSING THE RIGHT APPLICATION FOR YOU*



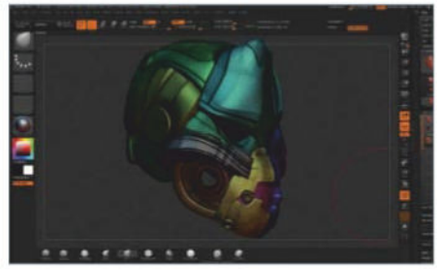
3DS MAX

3ds Max is frequently used by videogame developers, animators, TV studios and architectural visualisation studios, and it allows you to create organic objects as well as geometry. You normally start with one of 3ds Max's primitives or you can create your own topology and manipulate the surfaces by moving the vertices to create the shape you require. A lot of designers create their base model in 3ds Max, then import the mesh into another program.



SOLIDWORKS

SolidWorks is the world's most popular computer-aided design software and is mainly used by engineers and industrial designers. Creating a model in SolidWorks usually starts with a 2D sketch, which you can then adjust to define its position and size. SolidWorks also allows you to create assemblies. This allows you to virtually assemble parts, in turn allowing you to test if moving parts work and then make changes.

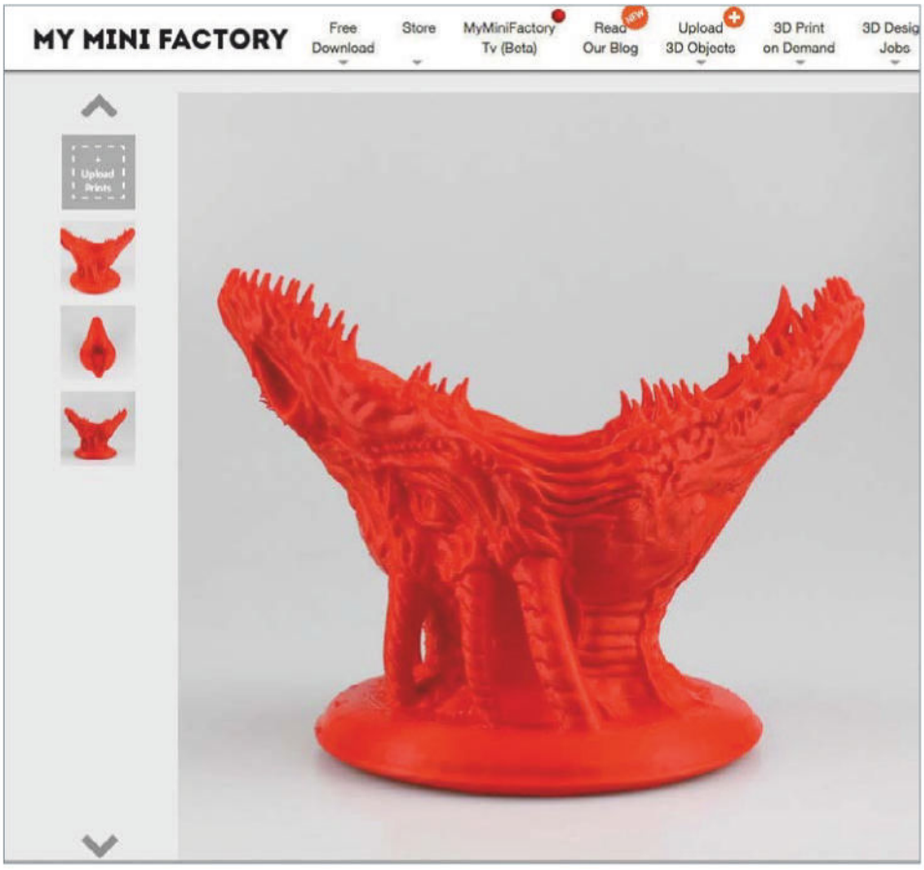


ZBRUSH

ZBrush is a sculpting tool used for creating high-res models and is, along with Autodesk Maya, one of the most widely used industry-standard 3D applications. ZBrush is particularly useful for traditional artists, allowing you to essentially mould chunks of virtual clay to create intricate sculptures. This artistic leaning, combined with the latest release's excellent modelling tools, make ZBrush a wonderful app for designers and enthusiasts.

ESSENTIAL MODELLING TIPS

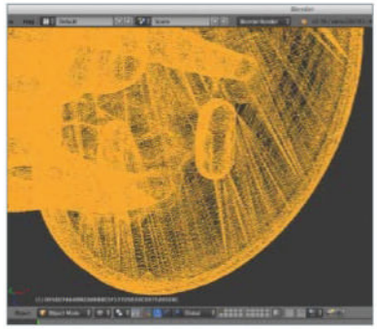
LEARN THE MOST IMPORTANT RULES TO DESIGNING AND MODIFYING YOUR MODELS SPECIFICALLY FOR 3D PRINTING



Choosing the right software to model potential 3D prints with is a surprisingly personal decision, with different software packages, slicers, and even plug-ins to choose from at a wide variety of price points. If budget is a major factor in your decision, Blender or SketchUp are great, free options. Your personal style should also be a factor. Anyone interested in modelling hard surface designs to print to very accurate levels should take a look at software better for CAD such as SolidWorks; but those more interested in organic-looking designs would be better suited to 3D sculpting packages like ZBrush or Sculptris.

Whether you're modelling an organic character or a mechanically complex vehicle model that needs all the right tolerances, taking a 3D digital design from software to printer requires a new set of skills. If you want to 3D print your piece you need to remember to always design for the real world – considering constraints such as the build volume, gravity, and strength of the final piece as well as how great it looks as a digital design. Knowing the rules for 3D printing will improve the quality of your final results, avoiding inaccuracy and mistakes.

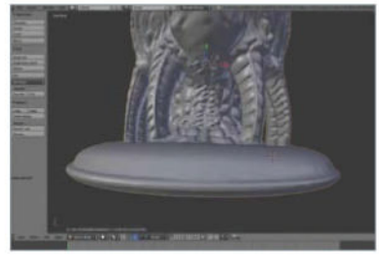
HOLLOW YOUR MODEL



In order to save on the cost of your 3D printing materials or on the cost of sending your model to a print vendor to print, it's a very good idea to make sure your 3D printable model will print as a hollow product instead of solidly filled with material. Prepare your final print file to be hollow while you are modelling by making sure your final design has both an inner and an outer shell – the distance between them will be the wall thickness when your model prints, so take into account the strength of the materials that will be used to determine how thick you want your model to be. Remember that even if in most software viewports a model will appear empty inside, a 3D printer could not interpret it as such unless a shell is created when modelling or in software such as MeshLab afterwards.

CHECK THE STABILITY

Crucial for functional prints such as cups or bowls is the ability for the final object created to stand up on its own. Consider adding a base to your finished model – and make sure that base is flat and hollow.

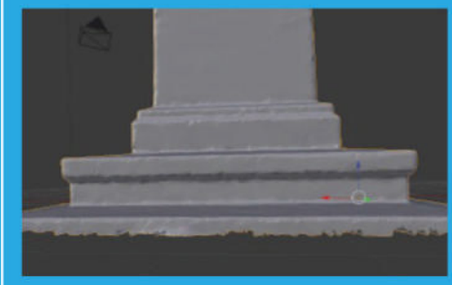


CLEANING UP HOLES

You might be used to modelling a character in separate pieces such as clothes, hair, and accessories, but for 3D printing the model will normally need to be modelled as a single seamless mesh without any open holes and with fully merged vertices and edges. This will ensure it is printed out without problems – software such as MeshLab and netfabb will do this automatically.

AVOID DISASTERS

Avoid 3D printing mistakes and disappointments with these tips on what not to send to print

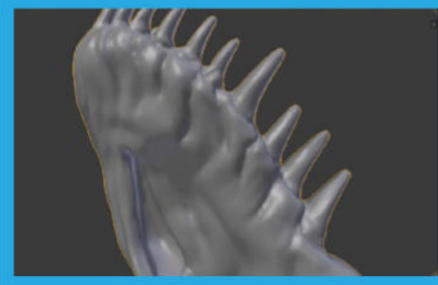


An unsteady base

Make sure the bottom of any model you intend to print is completely flat. This will avoid problems such as warping when actually printing and add to your model's stability when standing.

Pore-level details

Remember to not get too focused on every single crack and pore. Some printers cannot achieve the detail – remember to consider the mm resolution of your printer when modelling.

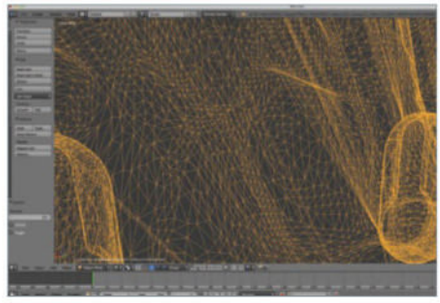


Too many overhangs

Don't allow any model to have too many unsupported overhangs. Remember the 45-degree rule – any unsupported angle in your model that's less than 45 degrees will normally require supports.

REDUCE POLYGON COUNT

When you have finished your design, actually converting your model into an .stl file or. gcode that the printer will interpret to print your final model will be much faster and easier if the overall model polygon count is lower. Take particular care in checking for any unnecessary polygons in your projects – such as any internal surfaces in an otherwise hollow design. Make sure you then triangulate the polygon mesh before slicing to save even more time so that your slicing software does not have to convert it for you –



Gcode generators need all polygons to be triangulated before being able to create the code for the printer to print.

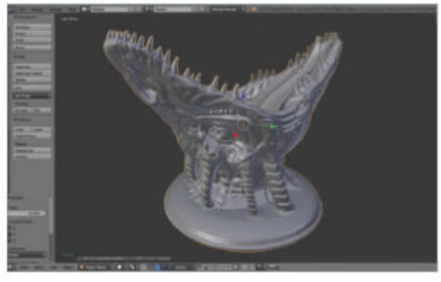
CHECK NORMALS AND GEOMETRY

Make sure your model doesn't contain any non-manifold geometry, or any one edge that is shared by more than two faces. Also ensure that all surface normals have a unified direction, pointing outwards away from the model's surface.

These can both be tricky to spot and correct directly in your modelling software, but as another option there are applications such as netfabb that can do this model clean up automatically, so you don't have to.

KEEP ORIENTATION IN MIND

Choosing the right orientation for your final model can allow you to avoid using too many support structures, print in less time, and even make stronger final objects. An object can be twice as strong if orientated with the layer, for example. The layers are the weakest points of the models so ensure the layers are running perpendicular to the area where the force is exhorted the most.



MODELLING QUICK TIPS

DIMENSIONS

Remember to make sure your 3D printed model will have the right dimensions and fit in the 3D printer's build volume – otherwise you may have to print the object in separate parts to then glue or fit together.

FLEXIBILITY

Using ABS plastic allows for some flexibility if so desired. But if you don't want any flex make sure the area is thick enough to not allow the part to flex.

SUPPORT MATERIAL

Try to design your model to print support-free so that no clean up is needed. Or try to create your own custom support in areas of your model that aren't too obvious.

TOLERANCE AND CLEARANCE

When deciding if any part needs to fit into another or any moving parts ensure you have tolerance – leave a small gap between two objects, even as tight as 0.3mm. Test your moving parts through clearance to ensure they will move how you wish.

EXPERIMENT AND SHARE YOUR MODEL

Experiment with different fill types, orientations, supports, materials and more to deliver the best result! Don't forget to share your model on **myminifactory.com**, **shapeways.com**, **thingiverse.com** and more so others can download and print it.

A GUIDE TO FINISHING

ENSURING THAT YOUR PRODUCT IS FINISHED PROPERLY IS KEY TO CREATING A HIGH-END 3D PROJECT

Imagine spending many hours crafting a beautiful piece of furniture and then leaving it bare. If you left it with just the original work in its natural state, it would not looked finished and would be half the object it has the potential to be. For all of the talk and hype surrounding 3D printing, finishing is rarely mentioned, but it remains a hugely important part of the creation process. From the initial inception to the very final stages, finishing should be considered. It is integral to how well the object will be received. You will need to think about sealing, bonding, painting, sanding and other stages of finishing your product during the idea formation. You need not be concerned that finishing the object will be too difficult. Many of the techniques and processes used in finishing a 3D object have been used for years on other materials and only require time and patience to complete. If you follow our tips and understand the materials and tools you need before you start, you should be able to complete the finishing process with widely available materials and tools you may already own.

In many ways the finishing process feels completely opposite to the process of 3D printing. The first part is designed to largely automate the process of building usable objects, but the finishing process will require a human to use their skills to add personality and class to the finished product. It may feel like a small part at the end of the process, but it really is important and should prove to be an enjoyable activity which brings you closer to the object that you have created. If you want to build an object of beauty or one that is practical in daily use, the finishing process is the final crucial stage in building a worthwhile 3D product.

"From the initial inception to the very final stages, finishing should be considered. It is integral to how well the object will be received"

TIPS FOR FINISHING

FINISH YOUR 3D PRINTED OBJECTS IN STYLE. PATIENCE, SKILL AND THE RIGHT TOOLS WILL HELP

This guide should help you understand the right approach to take before you start finishing your 3D prints and this will consist of general advice, tips for the best tools to use and some areas to avoid. The fact is that finishing a 3D object is very similar to traditional finishing of wood and metal, but with the provision that these objects can be much more complicated in form and potentially more fragile. You will need to take some time to understand how the various materials you use will work together and also be considered with the tools you are using. Lots of research, a safe environment with good lighting and ventilation, and the right tools will give you the confidence you need to spend time making your 3D printed objects look as good as they can. Without finishing, most 3D objects look like rugged plastic forms so the techniques mentioned here can make all of the difference.

WELDING FOR STRENGTH

You will want to weld 3D objects together if the requirement is for a very strong joint between the two, but the process will require specialist materials and equipment to complete. Research has been undertaken on metal 3D printing, but as we are in the early stages the costs are still extreme. This leaves us with the traditional methods which will involve using an oxyacetylene gas torch or arc welding which requires the use of high electrical currents to heat the two objects for bonding together. If you need to weld objects together, consider asking for help from a professional with the necessary tools to help you. The cost of arc welders is not too high, but you need to remember that if you have to repeat the process for different objects, new equipment or templates may be required each time and so it makes financial sense to build a relationship with those who already have the equipment and knowledge. A good quality weld could mean the difference between complete success or failure.

SOLDERING IS SIMPLE

The main advice when soldering two objects together is to ensure that both components are clean. You will want to remove any surface oxides, which may involve scraping them with a knife, at which point you should physically join them together to ensure that the mechanical joint is sound. It is only at this point that you should start the actual soldering process. Many people try to make a join through soldering which will eventually break as this process is not designed for strength under all circumstances. The trick is to attach the objects before you solder over the top of them which will create a stronger and more durable join. Soldering is mainly used for joining electrical components, but can be used for 3D printed objects as well, and this could be where brazing comes in.

Brazing uses a filler to join objects at a much higher temperature, but the actual physical process and tools used are very similar to soldering. You can use copper, silver or zinc as the bonding material when soldering, but aim for one with a high proportion of tin for the best results. Soldering skills will always be useful for your future projects.

SAFETY

Always consider safety before you start finishing

01 GLOVES

Take some time to find the perfect balance between protection and manoeuvrability. Some thin gloves can still be very safe.

02 GLASSES

If possible, try to wear safety glasses all of the time because you never know where danger may come from. Anti-mist glasses work best.

03 SOLDERING MASK

Don't be complacent. If you are expecting to solder 3D parts, you should always use a proper soldering mask to keep yourself protected.

04 FACE MASK

You should also consider dust and fumes so a face mask is a must-have safety option. They are also extremely cheap considering their benefits.

PAINTING

Take care painting your prints for the best results

01 BE PREPARED

Make sure you have the right brushes and paints for your prints ready before you start. Don't forget adequate ventilation and a source of water.

02 POROUS MATERIALS

Be aware that many 3D materials are porous so you can expect the paint to seep through to the other side on thin sections.

03 MODELLING PAINTS

You do not need to spend a fortune on paints because good quality modelling paints work well. Most acrylic paints will do the job.

04 BRUSH LIGHTLY

Brush as lightly as you can and use many strokes with minimal paint. Patience is key to painting a 3D object without any blemishes.

SMOOTH YOUR 3D PRINTS

It is extremely difficult to produce smooth 3D plastic prints immediately, but there is a process you can use to smooth them quickly. You can place a large glass jar on a heating build plate and then place your object inside. Add a tablespoon of acetone and heat it to 110°C, at which point the acetone vapour will react with the plastic and automatically smooth out the entire object, but you will need to remove it quite quickly. This trick works with ABS plastic, but does not with PLA materials so you will need to check carefully before you start.

FILLING

The process of filling on a 3D printed object is not as straightforward as you may first believe. You will need to use a putty like Bondo which is ideal for dealing with scratches and dents, but you will also need to spend some time sanding the area afterwards before it can be painted. This process will very much rely on the type of object you are filling and the requirement for absolute smoothness afterwards, so take some time to research the best methods to fill a particular area. It is a traditional approach which is used for much more than just in 3D printing so you will likely already have an idea of how to complete the process. Try to add the putty in very thin layers for the strongest and most visually pleasing end result. It can take time, but it will be worth it in the end.

SEALING YOUR 3D PARTS

There are sophisticated techniques that can be used to seal 3D parts, but there is also a product called TC-1614 A/B which can be utilised to strengthen and seal each component. You have to pour equal amounts of the included epoxy resin solutions separately and then heat them to 49°C. Pour them into a plastic bag and then place your object into the bag for 25 minutes. Once removed, you will need to leave it to dry naturally and the end result should be a fully sealed component which also looks much smoother than before.

GLUE WITH CARE

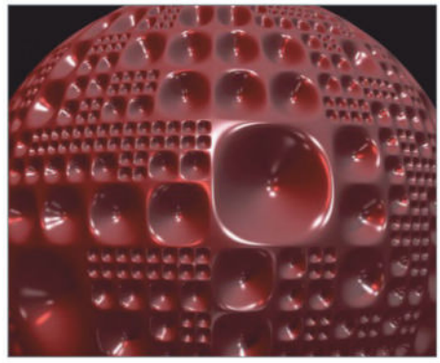
The first thing to consider when gluing a 3D printed part is whether this is the best option. You will need to be confident that the process will provide the strength you require and if so, we would recommend Cyanoacrylate, which is otherwise known as Super glue. This is ideal for small repairs and Araldite, a type of epoxy resin, is also an option, but we would tend to say that careful use of Super glue will give the best results. Please remember that glued repairs can be almost impossible to paint so use the glue very sparingly.

TRIMMING IS ALMOST ALWAYS NEEDED

When trimming 3D parts, the best advice we can offer is to consider exactly what you need to do before you start. You will need to understand whether scissors or knives can be used or if some simple sanding will do the job. It is, however, much more complicated than that because even the way you hold your 3D component while trimming can cause damage and completely ruin all of your work in an instant. If you are able to, try to secure your 3D part with a vice or similar tool and then spend a lot of time trimming rather than trying to get the job done as quickly as possible. There is no specific method that works for all types of trimming, but experience and patience will be your friends when it comes to trimming and the more you do it, the better the results will be.

POLISH TO FINISH YOUR WORK

You can polish a 3D object, depending on what material it has been cast from, using a standard polishing compound, but there is a lot of work that needs to be done before you reach this point. You will need to spend time sanding the object so that it is smooth and also trimming it to remove any unnecessary edges. A buffing wheel attached to a drill will speed up the process immensely and if your object is strong enough to cope with a tool like this, the end result could be much better than you expected at the start of the process. Finally, a product like Carnuba wax should be used at the very end of the polishing process and again you can use a buffing wheel to do this. Consider the size of the wheel and try to polish every part of the object evenly to create a finish which is positively gleaming. This step should be the most enjoyable as it represents the very end of your 3D printing process.



FINISHING QUICK TIPS

GET HELP IF NEEDED

Not all tasks in the finishing process can be handled effectively using tools and materials that are freely available. If you need to, ask for expert help.

BEFORE YOU FINISH

Consider what materials you are using in your 3D prints and if they can be finished using traditional paints and polish. Don't restrict yourself before you start the process.

CAREFULLY CONSIDER COLOURS

It is worth considering the colour that you are aiming for at the end of the build and if this can be included in the printing process rather than relying on painting later on.

3D PRINTS CAN BE FRAGILE

Take some time to practice finishing techniques on other objects that are not as fragile as your 3D prints. Experience will let you deal with fragility more effectively.

THE RIGHT MATERIALS

Only purchase positively reviewed and well-known products to finish your 3D objects. It is never worth saving a small amount of money on non-branded products.

YOU CAN'T GO BACK

Take the view that everything you do when finishing your 3D prints cannot be undone. If you prepare and research every step, you should be able to achieve the desired effect.

THE BEST TOOLS

The right tools will make all of the difference

The work area

Try to ensure that you have a spacious workbench to work on and ideally one with a vice so that you can finish objects precisely. Adequate ventilation is important when using glues etc.

Papers

Make sure that you have a selection of graded glass and sandpapers to hand as these will come in handy when finishing off 3D objects. The more you have, the better the finish will be.

Be sharp

Sharp knives of various sizes and larger scissors will also be a requirement throughout the finishing process. Please make sure you check them before use as blunt tools can ruin an object instantly.

GLOSSARY

UNDERSTANDING OF THE MEANINGS OF THE TERMINOLOGY

3D scanner
A device that uses lasers to 'record' the state of a physical object and render it digitally in 3D, enabling it to be printed

ABS
Acrylonitrile Butadiene Styrene is a commonly used non-biodegradable thermoplastic polymer

Computer-Aided Design
CAD techniques and software that allow a designer to virtually model an object in 3D

Extruder
The part of the 3D printer that melts and extrudes the filament through a hot end

Filament
The material (usually plastic) extruded to print the object

Fused Deposition Modelling (FDM)
FDM is a technique of 3D printing and is a trademark of Stratasys, so the equivalent term of FFF is often used instead

Fused Filament Fabrication (FFF)
The process of building an object from bottom to top by extruding filament, a different technique from FDM

Infill
Given in percentage or as a digit from 0 to 1, it describes how full or hollow your object will be

Maker
A maker is someone who creates objects using a 3D printer

OBJ
An editable object file, however unlike a STEP file this cannot be edited in all Computer-Aided Design software

Taper
Reducing the thickness of an object toward one end

PLA
Polylactic Acid is a biodegradable thermoplastic. It is used as a material for 3D printing and is made of renewable resources such as corn and sugar cane

Plane
A plane is a two dimensional surface

Print-bed
The tray inside the printer on which the object is built

Print speed
The speed at which a printer can extrude the filament. It's a very important characteristic of a 3D printer as a higher print speed can save a lot of time

Raft
A disposable base on top of which the object will be printed. It allows a better adhesion of the print and prevents warping

Resolution
Also called Layer Height, the resolution is the thickness of the individual layers of plastic used in a design

SD card
External storage device that can store different kinds of files. They are often used to transfer the 3D files to the 3D printer

Shell
The outside surface of a model

Spool holder
The part that holds the spool of filament

STEP
Another computer file format, this type of file is used for cross platform object creation

STL
STereoLithography is a file format that describes the surface geometry of a 3D object

Support
The disposable material used when an object has overhangs and needs something to print on top of

Tolerance
A small gap left between two parts to allow them to fit comfortably

Wall thickness
The thickness of the external wall of your model. Needs to be 1mm or more in order to print properly

WORKFLOW

BEFORE STARTING YOUR PROJECT IT IS WORTH DETAILING HOW, WHAT AND WHEN

GETTING STARTED

One of the most crucial aspects to 3D printing your first model successfully is to get started on the right foot. Something as simple as choosing the right type of plastic filament can make a huge difference in a print's final result, while taking the time to be well-versed in all the parts that make up your 3D printer help you fix things like a pro if something goes wrong. Here's what to consider when starting up.

Buying your first printer

As well as the budget you'd like to spend, remember to consider the types of materials the printer can use as well as the resolution and build volume.

- **Choosing the right filament**

There are a huge range of different filaments and other materials to choose from – including flexible, glow-in-the-dark, and wood or metal materials.

- **Levelling the print bed**

This will ensure your model comes out straight. Look at your manufacturer's instructions to level the print bed correctly.

- **Reading the instructions & finding support**

It might seem obvious, but reading the instructions that come with almost every consumer-ready printer today is one of the best things you can do towards setting a printer up to give you the best quality results possible.

Knowing printer parts

Don't know the difference between the print bed, Z Motor, and extruder? Learning the ins and outs of your printer will help you troubleshoot any problems that may arise with minimal stress and make the most of all the printer can do.

MODELLING

You won't be able to 3D print anything unless you have a 3D CAD model of the object you'd like to see brought into the real world. A variety of websites such as iMakr's myminifactory.com will allow anyone to download models suitable for 3D printing completely free. Otherwise, you can also learn how to use a range of 3D design software to create exactly what you'd like to print yourself.

- **Knowing what's suitable**

A model could look amazing on a computer screen, but be completely unsuitable for 3D printing. Make sure you know what to watch out for, including any parts that are too thin or a lot of unsupported overhangs.

Downloading models for free

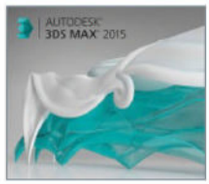
Visit websites such as **myminifactory.com**, MakerBot's **thingiverse.com**, or Ultimaker's **youmagine.com** to be able to download 3D printable models completely free.

- **Checking copyright or usage rights**

Before 3D printing any models, make sure you check over the copyright or usage rights related to the object to avoid any legal problems.

Learning the software

These days there are a huge amount of resources available to learn more, for all software. Check resources such as Digital-Tutors, CG Cookie, or 3D Artist Magazine.



- **Creating models yourself**

There is a huge range of 3D CAD software to choose from for 3D printing, from the free Blender or Sculptris to ZBrush and SolidWorks.

FINISHING

Finishing your 3D print by removing any supports, sanding, painting, polishing and more will truly take your work to the next level once it's out of the printer. This all-important step will give shine to your vehicles or make your life-size sword look truly metallic. Most 3D printed parts can be painted and polished to meet the cosmetic requirements for virtually any application.

- **Choosing the right equipment**

Part of finishing your model correctly and staying safe is to choose the right equipment for the job, as well as taking safety measures such as working in a well ventilated area when spray painting.

Removing support

This depends on the material used, make sure you research to find the best method whether it's simply breaking supports off by hand or hydrolysing in sodium hydroxide.

- **Practice**

Practice your finishing technique before using it on your final model. Never throw out your failed prints as these are perfect for practising with.

Staying safe

Remember than no matter how you choose to finish, it's crucial to stay safe. Wear equipment like goggles and gloves whenever possible – especially when dealing with acid, spray painting, or sanding down.

Choosing the right paint

Parts with a better final surface finish will be easier to complete through paint and polish, while any internal cavities could be a challenge to complete.

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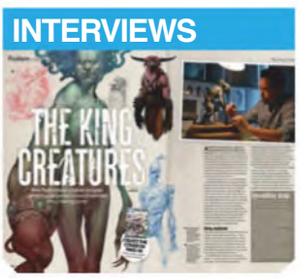

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PRINT

CONTENTS









Printer used	App name	Filament used	Complexity
Makerbot Replicator 2	SketchUp	PLA, 18g	● ○ ○ ○ ○

Create an iPhone 6 case

YOU CAN DESIGN AND CUSTOMISE YOUR OWN iPHONE CASE BY USING A FEW COMMANDS IN SKETCHUP.

If you own a smartphone, it's highly likely that you have bought a case to either protect your phone or make it look good (or both!). But have you ever considered modelling your own case? We're going to reveal how to use SketchUp to create a case for an iPhone 6, which you can then customise and 3D-print.

SketchUp is a quick and easy way to create customised 3D models, and being able to create your own case ensures you have complete control over how your phone looks. What's more, these steps will only take a couple of hours. The beauty of 3D printing is that you can create an infinite variety of objects and designs – you really are limited only by your creativity and imagination! We put this tutorial together in order to show how you can take objects from the real world, measure them and then create and customise models especially for you. Although we have focussed on creating an iPhone 6 case, you can apply the same techniques to all manner of objects in order to create accessories for real-world objects. And if you don't have an iPhone 6, simply adapt the dimensions to fit your own phone.

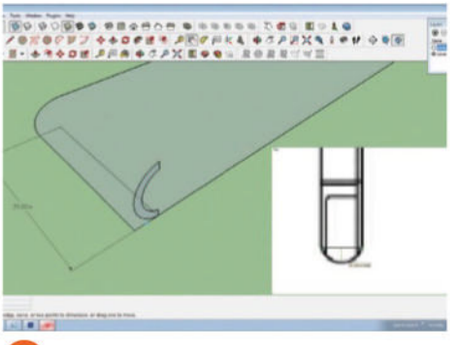
But for now, get ready to discover how to design and print the ultimate personalised protection for your beloved phone.

Maker: Cemal Cetinkaya is a product and award-winning jewellery designer who always aims to create aesthetic, innovative products with real functionality

Profile: myminifactory.com/users/ccetinkayaDowney

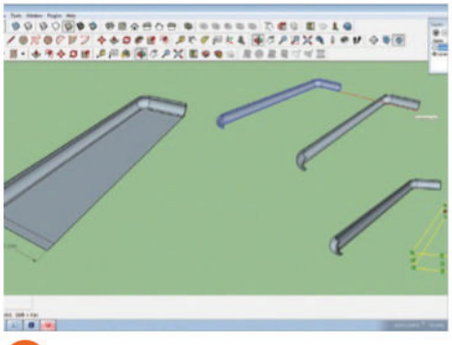
01 TRACE AND DRAW LINES

Import and trace a reference JPG that shows dimensions; use the Line tool, and the 2-Point Arc for curved edges. After drawing the main body, our guide plane appears between the lines. Use the Dimension tool and measure the main body. The iPhone 6 is 138 mm high, but make it 140-142 mm due to the tolerance.



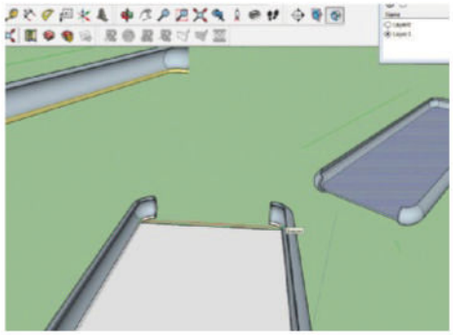
02 MODEL ROUNDED EDGE

Use the 2-Point Arc to trace the rounded side edge. Select it, click the Offset tool and type 1.2 to duplicate the line and set the thickness. Draw through the middle of the guide plane, top to bottom, and delete half using Eraser. Click Rotate, select the plane and move 90° to make it perpendicular to the guide plane.



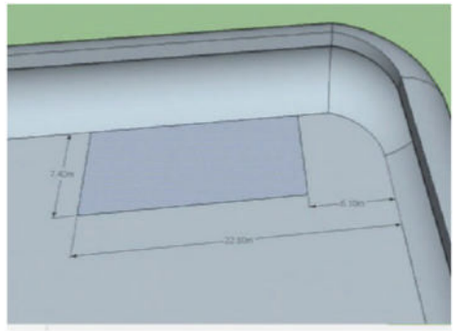
03 DUPLICATE THE SIDE

Move the section 25 mm from the middle point. Click Follow Me, select the section plane and move along the side of the guide plane. Hold Ctrl/Cmd and use Move to duplicate the body. Select the second part, click Scale and move the red snap point to the other side to flip. Join the parts with Move.



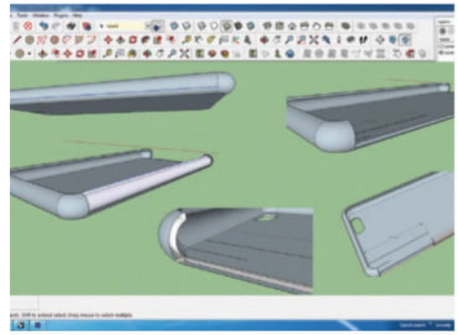
04 MODEL BASE SURFACE

Select the bottom edge surfaces and press the Delete key. Make another surface between the empty gaps. Click the Line tool and then draw a line by snapping the end point shown in the picture. SketchUp then makes a new surface and closes it. Do this for the other side.



05 MAKE A CAMERA HOLE

Measure or use blueprints to get an exact location for the camera hole. Use Line to draw a rectangle on the surface with the pictured dimensions, then 2-Point Arc to round it off. Select the lines and click Offset to create a copy inside and on top of it. Use Push/Pull to push the surface 1.2 mm inside.



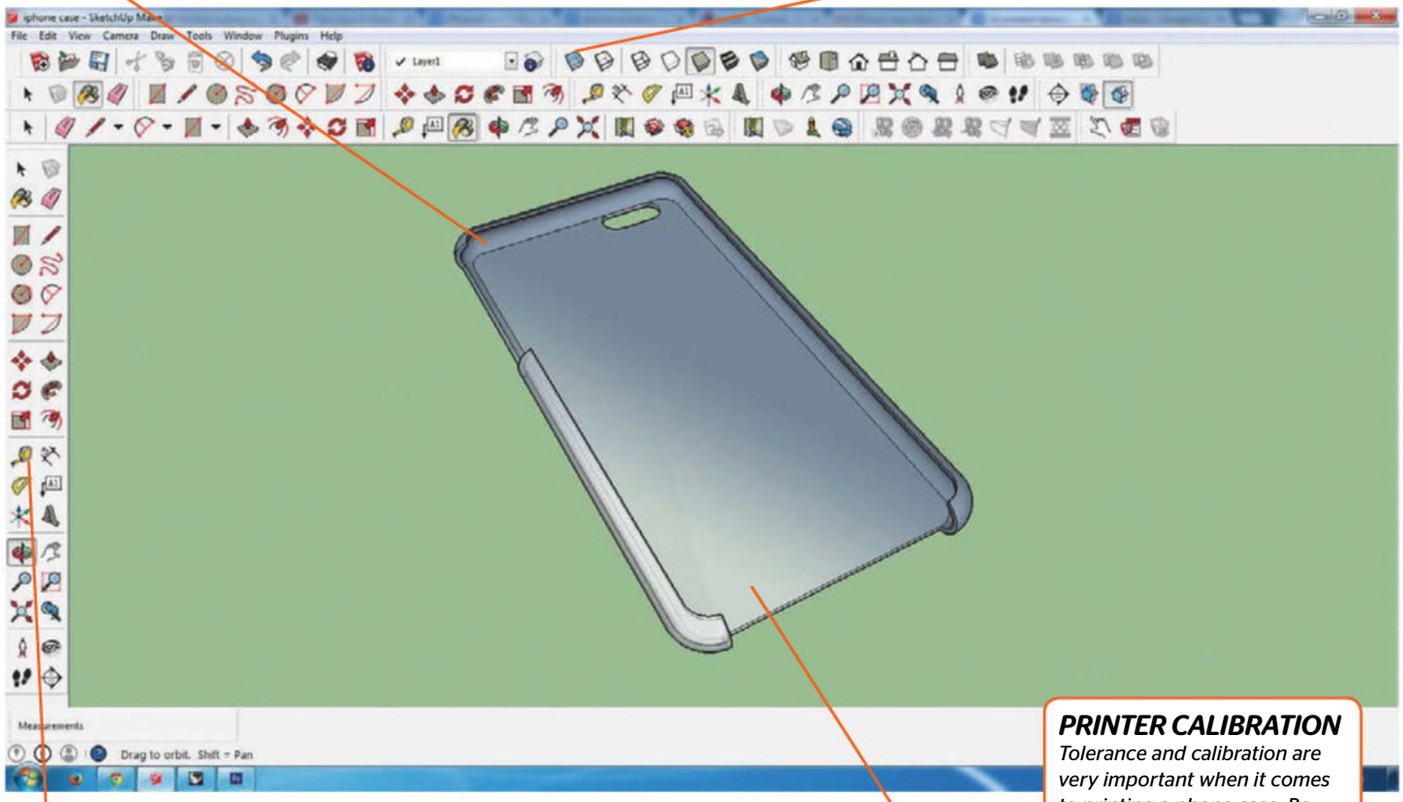
06 ADD FINAL DETAILS

Draw guide lines (14/50 mm) on the bottom surface, one on the side surface, select the surface between them and delete to open up the side for the buttons. To close, draw lines at the corners. Select the side surface and use Follow Me. Repeat until it reaches the guide line. Click File and export as an STL.

MODELLING AN iPHONE CASE

Tolerance is to do with the accuracy and size that your 3D printer can achieve. It is the most important consideration here because your phone needs to fit perfectly

It is sometimes useful to use the X-ray mode for transparent faces, so you can see the interior of your model. It can be very useful for your guide lines



Draw some guide lines to ensure that you can model your case using the exact size of your phone – it might help to make a to-scale model of your phone to work with

The case needs to be a little bit flexible so that it can be snapped onto the phone, so change the thickness of your case according to your own experience

PRINTER CALIBRATION

Tolerance and calibration are very important when it comes to printing a phone case. Be sure your calibration is sorted and you give the right tolerance to the case. You can always increase the tolerance, just to be sure it is okay after printing.

PRINTING OUT YOUR iPHONE CASE

Filament comes through the hole at the tip of this nozzle in the extruder – don't get too close as it's very hot!

01 LAYING DOWN THE BASE

Once you've sliced your model, loaded the files and started the printing process, the extruder will begin zipping around the printer bed and laying down the first layer of filament.

02 WORKING UP THE DETAIL

As you can see here, the filament itself is applied with a pencil-like tip, being gradually drawn on following the path defined by the g-code that your slicing software generated.

The whole extruder apparatus, or print head, moves back and forth rapidly during printing, building up the print in layers

Particularly with patterns like this, always print a test piece to check the tolerance is okay and your design is nice and crisp

03 REMOVING THE PRINT

Once the printing has finished, remove the platform that your print is stood on, if that's possible with your printer. This is so you can remove the print more easily and without breaking it.

04 FINISHING THE CASE

Depending on the tolerance of your printer, you may have some cleaning up to do. Here you can see that the edges of the case need to be smoothed and some irregularities removed.

Printer used	App name	Filament used	Complexity
Ultimaker 2	ZBrush	Form Futura	●●●●○

In this tutorial, we'll cover the main phases of sculpting an articulated muscular model using a skeleton geometry imported from SolidWorks.

Starting from a template of bones and joints externally modelled in SolidWorks and then adding decent details on top of it in ZBrush could be a challenging project. The biggest problems are related to the possible loss of accuracy of the mechanical parts. You will need to consider the compromise between the overall details placement and the need to maintain the joints with the same shapes and on the same precise location.

To explain the workflow, we'll split the project into sub-problems with the easiest solution for each. The starting point is creating one polygroup for each articulated part of the template, then Dynameshing them with high resolution in order to have dense sculpting surfaces.

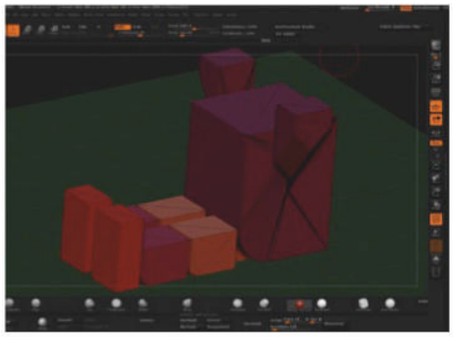
After this phase, the remaining steps will consist of analysing each part and evolving its design (for instance, the sculpt of the muscular arm) without impacting the moving systems of the model. This is why we explain how masking, selection and polygroups were so important in completing the project, using them in combination with other ZBrush features as Dynamesh, Zremesh, Backface Masking and different kinds of brushes to delineate the final design.

Maker: Francesco Orru is a 3D character artist studying for an MA in Computer Animation at Kingston University

Profile: myminifactory.com/users/4theswarm

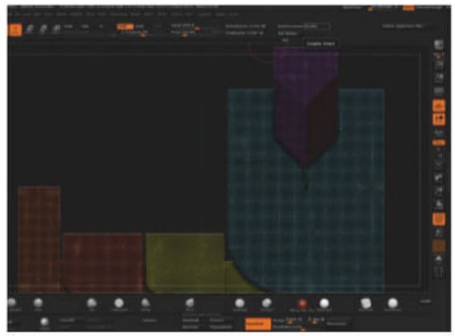
Design a model

OUR EXPERT REVEALS HOW YOU CAN ACHIEVE A STYLISED MODEL IN ZBRUSH, STARTING WITH A SKELETON IMPORTED FROM SOLIDWORKS



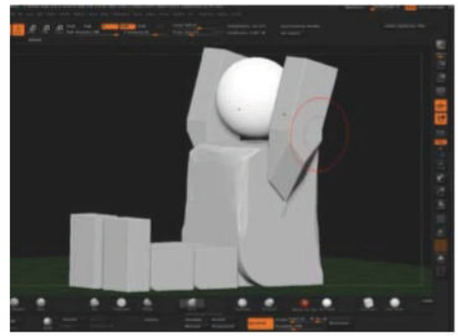
01 ORGANISE POLYGROUPS

After importing an STL from SolidWorks into ZBrush, we need to organise the parts into single polygroups using the Select Lasso and Select Rectangle, holding Ctrl/Cmd+Shift to hide or reveal polygons to keep together in one group. Use Shift+F to view polygroups and Ctrl/Cmd+W to create a new group.



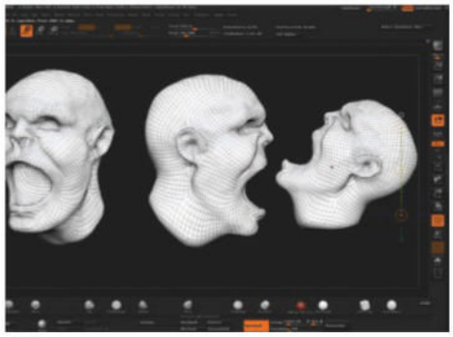
02 DYNAMESH THEM

For each part that's a separate group, we should Dynamesh or Zremesh it to have a different polygon density to the original skeleton. Dynamesh with a high resolution value between 700 and 1000; this is faster than adding single-edge loops for each part. Use Zremesh to work on a better topology.



03 INSERT THE HEAD

This is the only part sculpted from scratch and it has been merged in a second time with the torso. Given that we are still in a planning phase of the project, it is not yet important to do a fully detailed head. Focus mostly on fixing the primary shapes and moving forward with the next subtools.



04 NOW EXPERIMENT

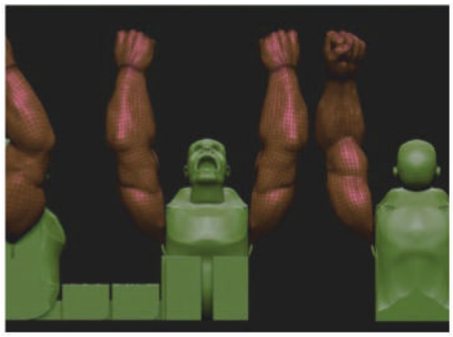
Use Clay Tube, Trim Dynamic and the Move brush to create the primary forms. These are good main brushes for blocking out the main forms and planes of the head. Exploring poses based on different reference images is a particularly intensive and recurrent part of the process.

05 MASK THE TORSO

After posing the sculpt of the head for a while to find the right look for your model, start masking the joints areas on the sides and on the bottom part of the torso, and sculpt on the unmasked surface using Trim Dynamic and the Move brush to slowly find a silhouette that looks satisfying.

06 EXTRUDE THE ARMS

To sculpt the arms, extrude the original Dynamesh geometry of the skeleton with the transpose line in Move mode and use the masking tools to protect the base from any modifications. After that, fix the volume of the main muscles and try to give a realistic look to the pose.



07 ZREMESH THE ARMS

Once you have a good amount of detail and the proportions are fixed, Zremesh the arms to modify the joint structure. Add a couple of subdivision levels to sculpt the hand and keep a good topology. For the fingers, apply Backface Masking on the Move brush to preserve areas facing away from the sculpting.

08 MAKE THE TORSO

The torso is tricky because having four articulations inside requires more accuracy during the sculpt. Mask rectangle, Lasso and Pen enable you to start blocking out the general anatomy. Use Clay Tubes for the volume, then Move with really low intensity and Dam Standard to accentuate details.

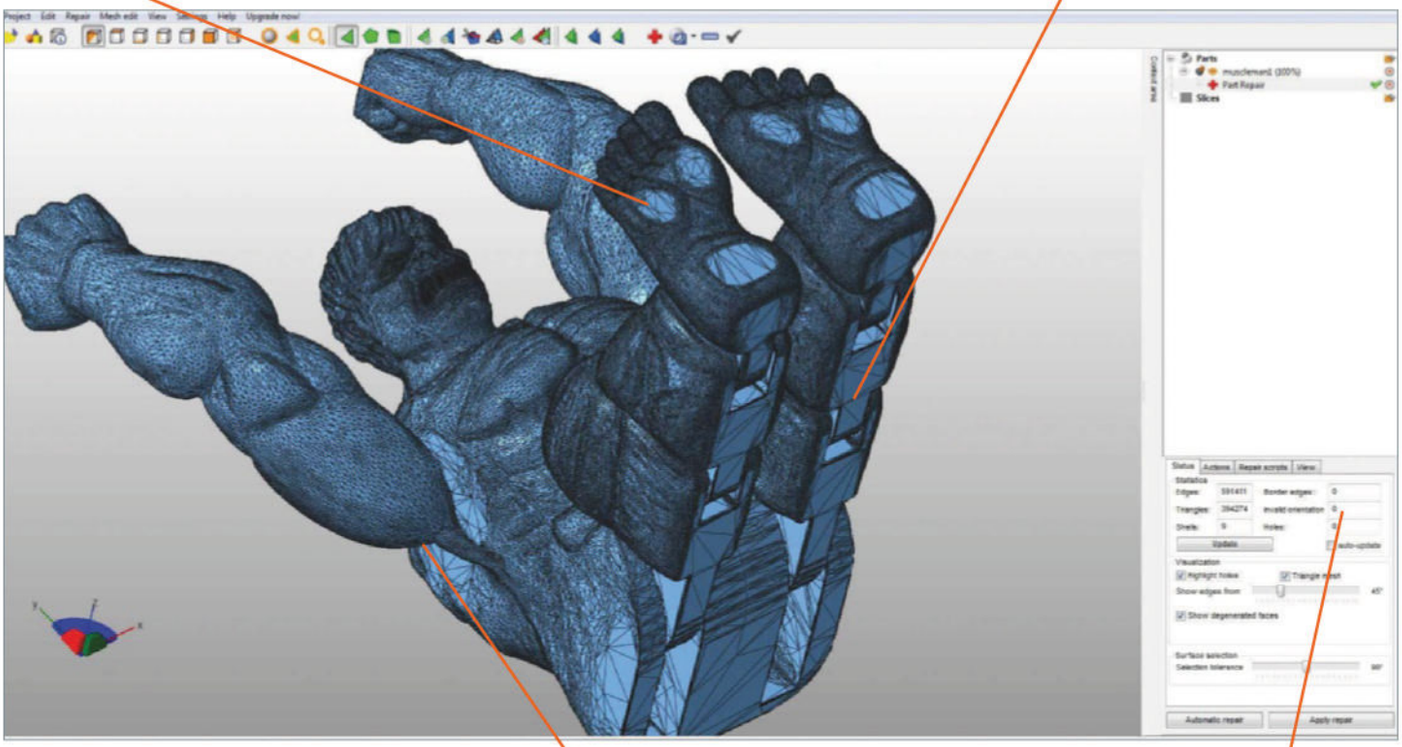
09 EXPLORE THE HEAD

You may have to switch a lot between the different components of the model during the first phases to study the direction that the entire piece will take. Keeping the head sculpt entirely free on a separate subtool helps because you can merge it with the torso later. Work on volume, not the detail.

FIXING MODELS USING NETFABB

The repair function will find any broken surfaces or deformities within the STL file. What the tool will do is highlight the area and attempt to fix the surfaces by either closing up a hole or filling a gap

Shells need to be repaired until we get the same number of separated parts in ZBrush – six for the legs, one for the torso and two for the arms



USE NETFABB PROFESSIONAL

If you still encounter problems fixing the geometry in Netfabb Basic, you can find an easy solution by switching to the Pro version of the software – you can have a much better view of your model.

Like with all CAD software, sometimes edges do not line up or connect like they should. Most of the time you will need to repair these; this is to ensure that all the edges are intact and joined to one object

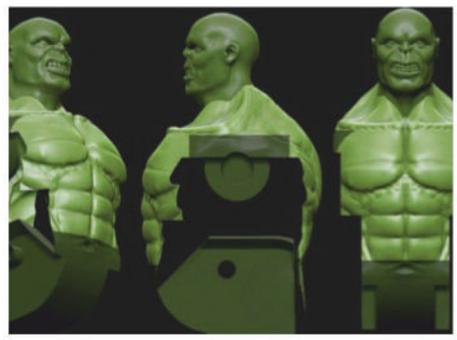
The Invalid Orientations value in this panel will need to be zero in order for you to get a successful export after scaling your model

10 REFINE THE TORSO

Continue with the anatomy, trying to achieve realism in the front packs and back muscles. Still in Dynamesh with a polycount of almost one million polygons, add more brushes on top of the body. Correct the proportions from the side view and decrease thickness in places such as the base for better printing.

11 SCULPT THE TEETH

To sculpt the teeth, simply create a Sphere and then Zremesh it after applying some clip brushes to resize the shape. After placing this new subtool in the correct position, play around using the masking tools and the Move brush with the Backface Masking option activated.



12 MASK THE JOINTS

You'll find that one of the most recurrent steps in this project is to use the selection tools and masking to hide and preserve the joints areas. Sculpting on top of the arm sockets or on the bottom of the torso is possible only if you constantly switch between different views with Select Lasso on.

13 MERGE THE HEAD

Now test out a merging of the head with the torso; this is to study and correct some shapes and proportions, as well as to see the upper area of the model all together in one piece. Then Dynamesh again with your new subtool and use the Select Lasso in negative mode to see the result of this first test.

14 ADD HEAD DETAIL

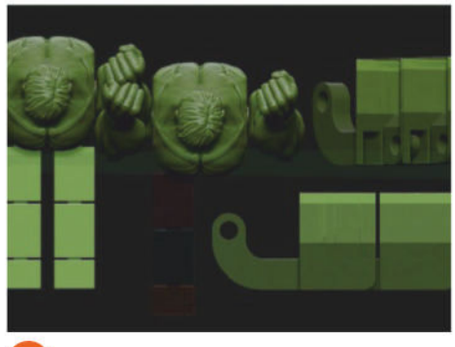
Adding secondary forms to the Dynamesh head is another way to obtain a more interesting and organic look in the facial features. Apart from blocking out the cheeks, temples, eyes, nose and skull, it is important to define an angle for the chin and the neck for a free support, as well as for the ears.

15 ZREMESH THE HEAD

After splitting the torso and head into two different polygroups, Zremesh the head to improve topology and fix polygons in areas like the teeth, eyes and hair. Duplicate the subtool before Zremeshing, especially as we want to transfer the details from the original Dynameshed model to the Zremeshed one.

16 TRANSFER DETAILS

With just the Zremeshed and original subtools visible (i.e. Zremeshed head and torso Dynameshed in both subtools), use Subtool> Project All. For each subdivision level added, project the details again until you get decent density and details. Delete the old subtool and Dynamesh again for a clean bridge.



17 PLAN THE LEGS

After finishing the upper body, define the anatomy of the legs. Focus on one leg, split into three polygroups. Mask the base, corresponding to the position of the joints, and extrude the leg with the Transpose line in Move mode. Dynamesh with a high resolution and get ready to sculpt the pieces.

18 SCULPT THE LEG

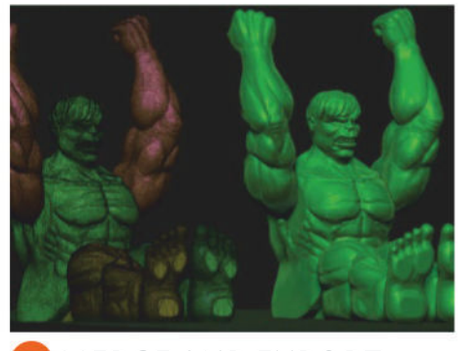
Focus on the front and border edges for a smoother effect. Joint areas need to be sharp as possible, so mask the central-bottom parts where articulations were placed. Use Trim Dynamic, Curve Tube, Dam Standard and the Move brush for general shapes and the foot, Dynameshing a couple times until satisfied.

19 MIRROR THE LEG

Once you have one leg completed, you can easily use a friendly plug-in called Subtool Master and click on the Mirror function to append or directly merge a new subtool, selecting the preferred axis. In this case we've mirrored on the X axis and after that we just merge down the leg.

20 DECIMATE AND EXPORT

Decimation is a must in 3D printing because we need a relatively short slicing time. Mask the joint areas then pre-process the subtools to 50k polygons in order to protect sharper zones against any stretching. Now click on Decimation Current, maintaining a percentage of 40% to keep good details.



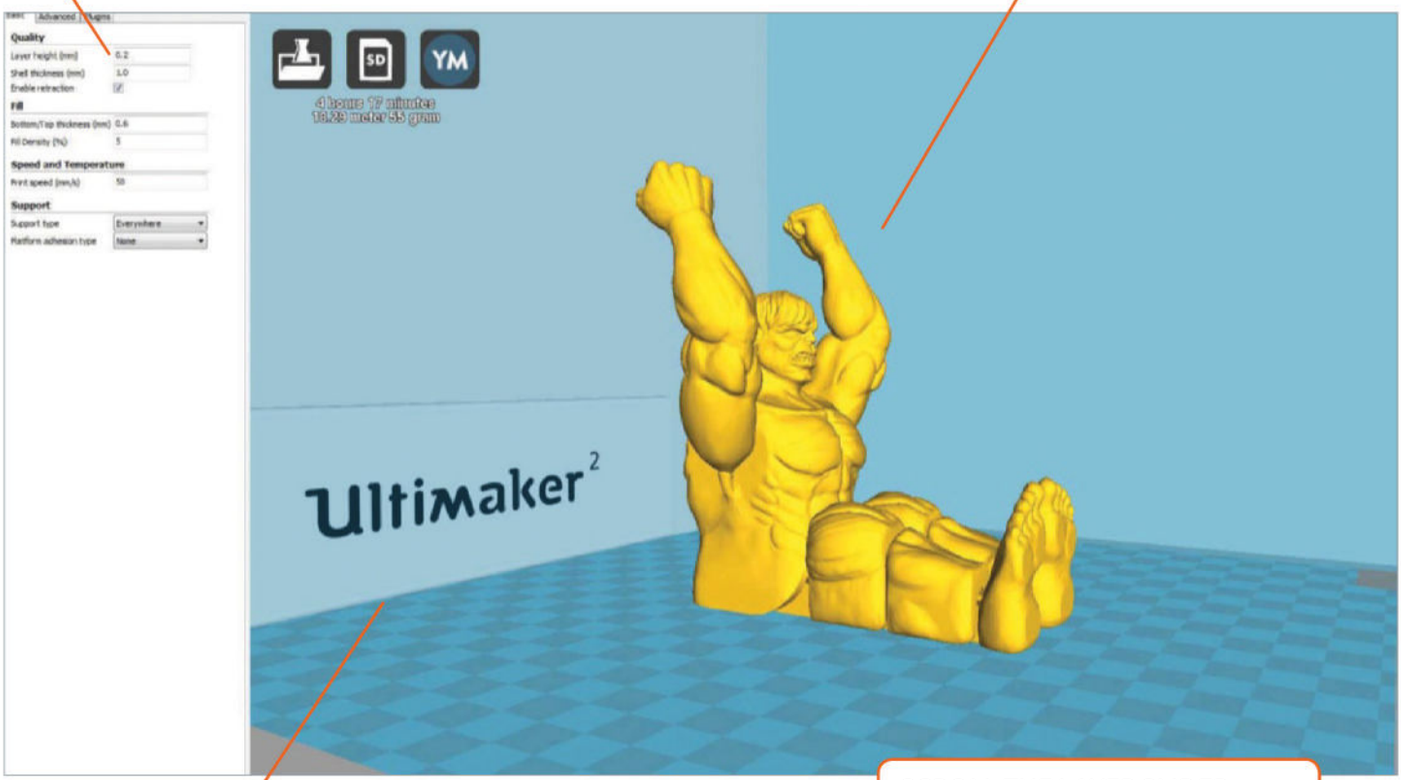
21 MERGE AND EXPORT

Finally, merge everything together to obtain a model with 200k polygons. After exporting using the 3D Print Exporter plug-in under the Zplugins palette, test for any possible shell problems using the Netfabb software and verify the printing speed under different setups in Cura and MakerBot.

ANALYSING THE PRINTING TEST

Keep a Layer Height of 0.2 and a Fill Density of 10%. Also ensure there is no brim and no support. These settings are important as they result in a good quality, detailed print in a short amount of time. The higher the percentage of infill, the longer it will take

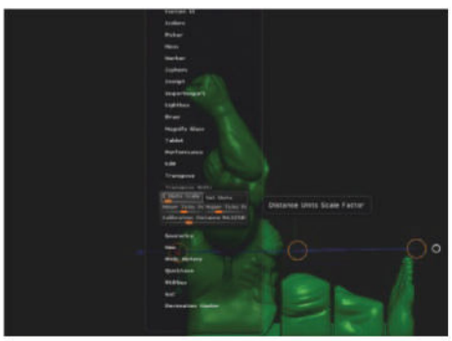
After importing, be sure to rotate the model and have a flat layer to start the print. Orientating the object correctly is what sets apart a good print from a bad one; you want to orientate your object so that it starts to print on the flattest surface possible to avoid rafting and support material



The slicing time for this model is very fast because the polygon count is under 200K – in our tests, we managed to get a slice in less than 15 seconds

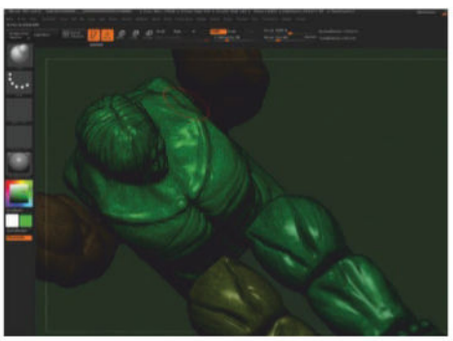
SCROLL THE LAYER SLIDER

Working on really complicated models means that it's highly recommended you adjust the Layer Slider to see the printing preview at different moments.



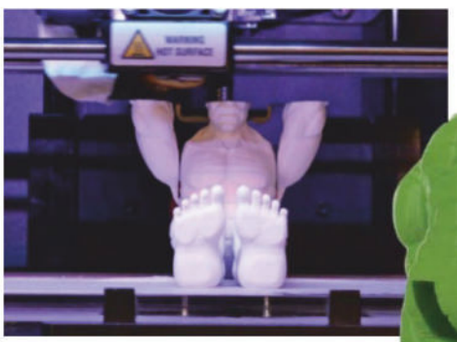
22 DOUBLE-CHECK GAPS

Before you export, double-check the gaps between the different parts of the model that were previously scaled. The Transpose line tool helps you get precise measurements if well configured; find the Transpose Units subpalette within Preferences then set the unit scale to 1 and switch to millimetres.



23 ADJUST THICKNESS

Pay attention to thickness problems that arise in the first tests, as these cause holes and unexpected effects in the geometry. Open the STL in ZBrush and use the Inflate brush in additive mode with Backface Masking on to expand the torso geometry, pushing vertices along their own normals.



24 RUN THE FINAL PRINT

The last thing in order to see your creation is to open the Makerware slicing software. Choose the setting with no raft or brim – this is important because you don't want to generate a flat plastic plane on the platform. Start the print and grab your paintbrush!

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Printer used
MakerBot Replicator 2

App name
SolidWorks

Filament used
PLA, 325 g

Complexity

Build a laser blaster prop

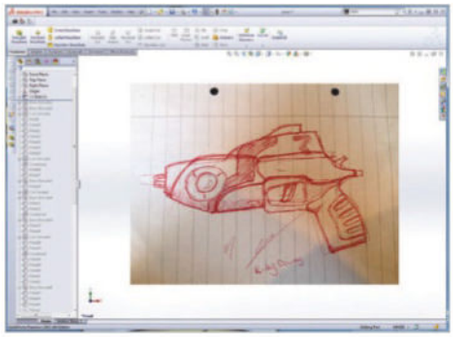
HAVE YOU ALWAYS WANTED THAT ONE PROP FROM A GAME OR A MOVIE? THIS TUTORIAL WILL SHOW YOU THE BASIC STEPS ON HOW TO ACHIEVE THIS

In this tutorial we are going to show you how to create and 3D-print a prop, which will include moving parts. Creating an object that incorporates moving parts can be tricky but is often a lot more rewarding. It encourages you to explore the limits of what your 3D printer is capable of and at the end of it you'll have a finished product, ready to take to your next Comic Con! Be prepared for a bit of trial and error when designing objects with multiple components that fit together; making sure that all your parts have the correct scales and tolerances can involve a bit of work, particularly if you want them to fit together without glue, however once you get the hang of it then it is a great skill to have!

We will show you how to create a 3D model from simple reference images and sketches. You will learn how to create moving objects within the model and how to test them to ensure they will work in reality. You will be shown how to cut the model and create glue-free joints so it can be assembled without any glue, and how to slice you file with the best settings to get the best results out of your 3D printed prop.

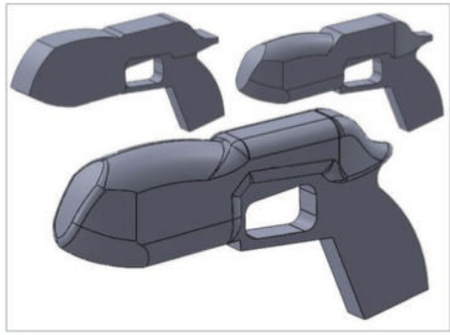
Maker: Kirby Downey is a product designer from South Africa. He specialises in taking, first making it work mechanically before adding a story to the product using shapes and forms

Profile: myminifactory.com/users/Kirby%20Downey



01 USE A GOOD REFERENCE

Having good reference images helps to figure out what details are necessary. Good references can help establish a sense of scale and size so that you can work out how many pieces will need to be cut. Use this to plan your workflow and keep in mind what is going where.



02 TRACE AND SHAPE

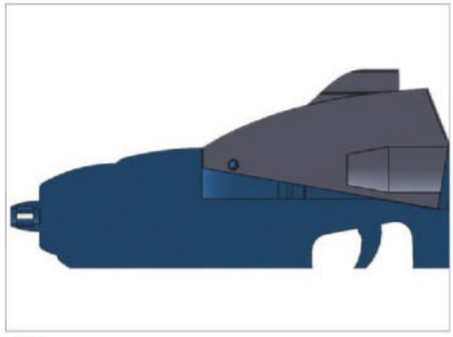
Begin the model by tracing the basic outline within the area that will contain the majority of the body and start adding and removing material from the model to create the desired shape. All the commands used are the basic Cut and Extrude commands, with Fillet and Chamfer used to add detail.

03 DETAIL AND FINISHING

When adding details, keep in mind that any details more than 1 mm deep or overhanging will require support material. If this detail is important to the aesthetics of the model, add 45-degree chamfers so the detail can print support-free. Once the model is complete, begin modelling the moving components.

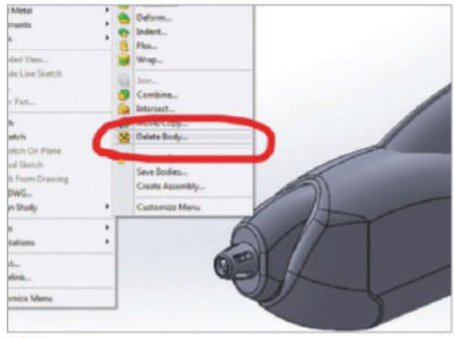
04 CREATE THE MECHANISM

Creating the reloading mechanism, which will flip up out of the top of the prop, is simple if you keep in mind the tolerances that are required in order to make it work successfully. The rule of thumb is that tight fits like clips and joints need a space of 0.3 mm between the bodies.



05 CONSIDER TOLERANCE

For loose moving fittings, like the reload mechanism, try using a 0.5 mm space between the bodies. This will enable the chamber to move freely. Create the reload mechanism and the chamber as separate bodies within the same build. You will test the movement later when making an assembly.



06 DELETE THE BODIES

If you delete the bodies around the chamber and mechanism, you can save them as individual parts. Use Insert>Features>Delete Bodies to select what you don't want – for example, delete the main body of the gun to leave the chamber, then save this with a new name. Repeat, deleting the chamber this time.

07 CREATE AN ASSEMBLY

Put the parts into an assembly and move them around the environment to ensure the chamber won't touch the body. Start by inserting the main body, then insert the reload mechanics. Use concentric mates, so you can move the mechanism and chamber to see if it clashes with any other bodies.

08 SLICE AND DICE

Once you are satisfied, cut up the main body to fit your printer. Keep the size of the print bed and the orientation in mind. The zig-zag joints are designed to be snapped together without glue, with a gap of 0.3 mm to allow for a tight fitting. When finished, delete the parts one by one to save them individually.

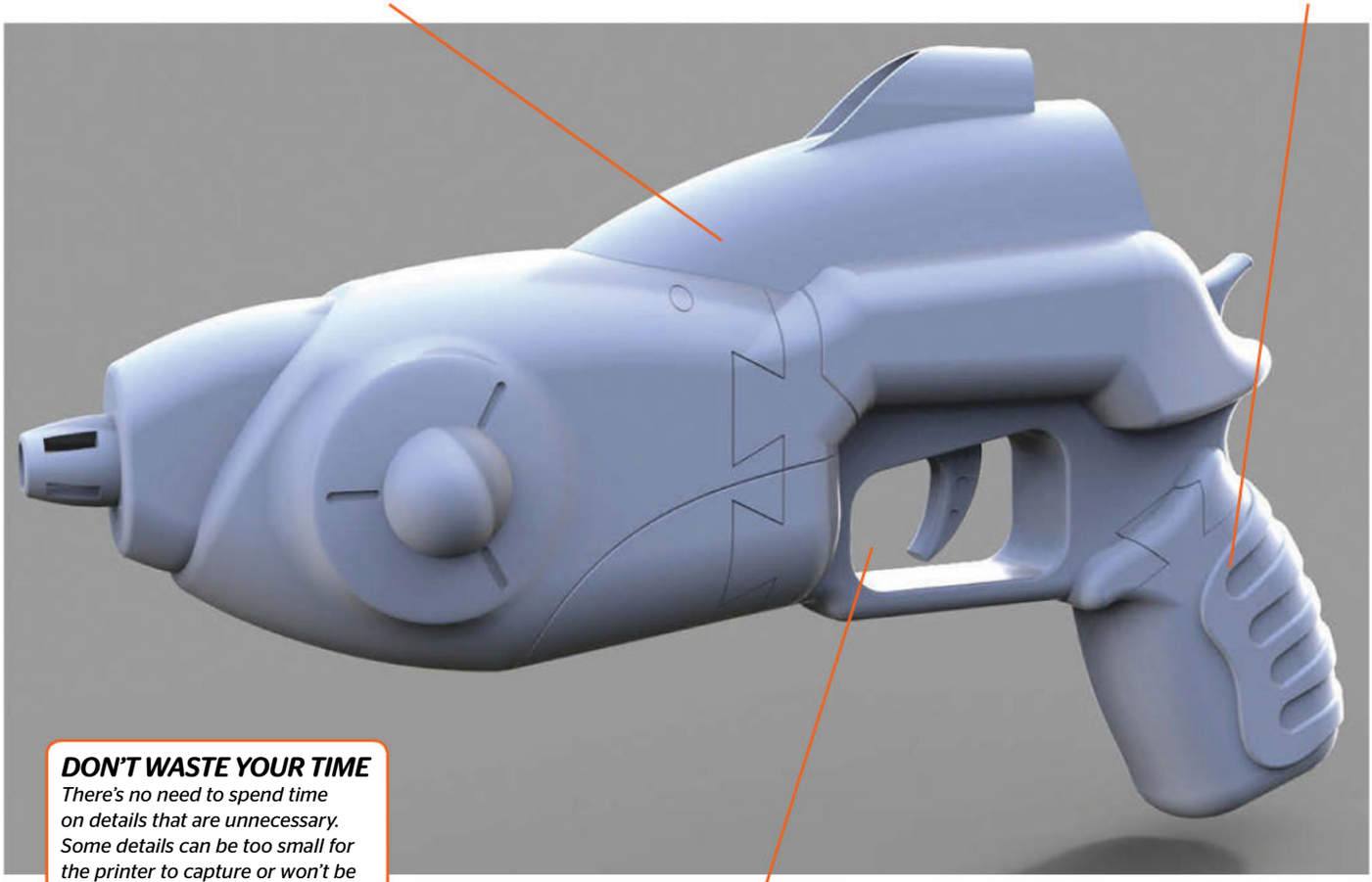
09 FINAL ASSEMBLY

Once you have the separate parts and have saved them, you will need to put them back together in an assembly to ensure the snap fits you are going to create in the next step will line up perfectly. Only insert the reload mechanism and the chamber once you have completed the snap fit creation.

PRE-PRINTING CHECKLIST

Check the mechanism works and is clear from any collisions with other bodies. Testing it before you print will prevent you from having to throw away lots of failed prints

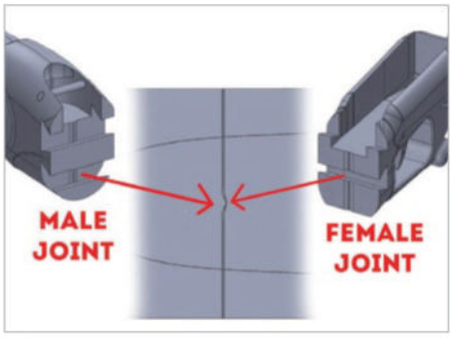
Ensure you are happy with the details added or decide if you would like to add more. The straps created here can be excluded and torn white cloth can be wrapped around the handle instead



DON'T WASTE YOUR TIME

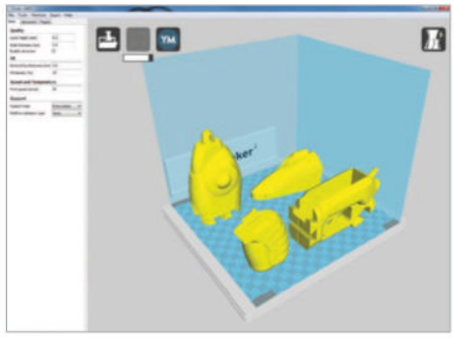
There's no need to spend time on details that are unnecessary. Some details can be too small for the printer to capture or won't be captured successfully. If you are unsure of a certain section, isolate and test print that section. Some details will look better painted on.

Make sure you have tolerance for everything and the tolerance is correct to the application needed. Test-print just a small section if you are unsure



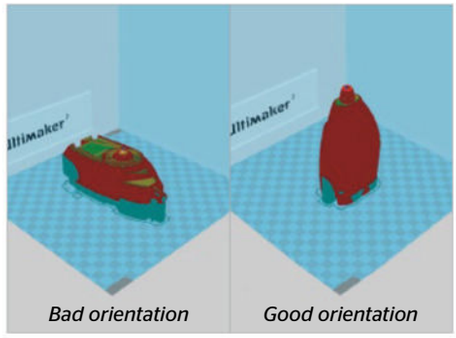
10 CREATE THE SNAP FIT

This is the tricky part of the build. This involves putting in a notch that enables the parts to snap into each other. The male notch should be 0.5 mm high and the female notch should be 0.7 mm deep. In the image you can see a simple diagram showing the profile of the notch.



11 SEND TO PRINT

Now that you have completed the fittings and are completely happy with your model, you can save the files in the STL format in order to send to print. Open your slicing software; we are using Cura but there are many that can be used. In here you can see your 3D models and how they fit on the bed.

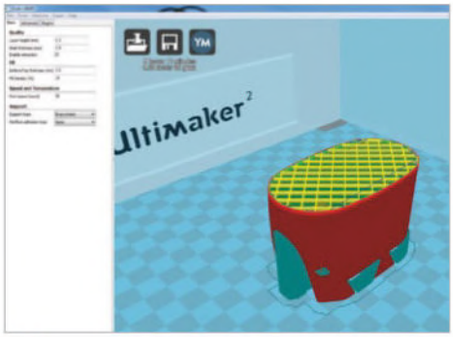


12 SET ORIENTATION

Import the files into your slicer. Orientation is key to getting clean models quickly. Here you can see the model in red and the support in blue, and two different orientations. What makes the one on the right ideal is that it has less support material on it, which will make it easier to clean and lead to less scarring.

13 SET LAYER HEIGHT

Some print settings are just as important as optimised details, as they change the time and quality of the details. Printing at 0.2 mm per layer is fine for models with long, flat surfaces like this prop, but with highly detailed sculpts it would be better to use 0.1 mm, though this will increase the print time.



14 SET INFILL

Infill is the honeycomb structure inside a 3D-printed model that enables it to be strong and lightweight. Infill can also add weight and strength, if needed. With this model, 10% infill (ie 10% of the interior will be material) is enough as it needs to be light enough to be carried, but won't break if it gets bumped.

15 REMOVE SUPPORTS

Once you are happy with all of your settings, print out all the pieces of your prop gun and then remove them from the printer. The best way to remove the support material is to use both a putty knife and a crafters knife. You can also use small files in order to help get the moving parts working smoothly.

16 ASSEMBLE AND PAINT

To assemble, slot the parts up to the notch and knock into place with a rubber mallet. It is easy to paint on printed parts and you can use any on the model. We used a white acrylic undercoat then masked off the areas that didn't need the red and blue paint. Use a clear coat spray paint to protect the paint.

17 THE FINAL PRODUCT

Once the final product is printed, you have cleaned off the support material, assembled it and painted it, you'll have an amazing final product that you can touch, hold, play with and show off to your friends. And now that you've made your first moving parts, you can experiment with them in other models.

FINISHING TIPS

IF YOU'RE FEELING CREATIVE, WHY NOT TAKE A REFERENCE IMAGE FROM YOUR FAVOURITE GAME? KIRBY FROM iMAKR DESIGNED THIS AMAZING REPLICA OF THE THORN GUN FROM *DESTINY*!

If you want to embellish your painted print with surface art, use masking fluid or tape to cover the areas you don't want to accidentally paint over

Depending on how well calibrated or how accurate you printer is, some tolerances will be a bit looser than expected. Glue can be used to fix parts that are a little wobbly. With the zig-zag joint you don't need a lot of glue to fix it

Careful painting is key to a model like this. Start with a light acrylic coat and build it up from there

PLAY WITH YOUR PRINTER

The only way you will know how your printer performs at its best and which settings work best is by playing and experimenting. While modelling, if you want to see if detail will appear, or if a certain section is strong enough or if it can get away with no support, test-print just that section and experiment. Once you understand how your machine can handle certain models, you can start making better, higher-detail models to push your machine's limit.

DON'T THROW OUT THE OLD PLASTIC

Use your failed parts and test pieces to experiment with finishing and painting techniques. For example, ABS can be bathed in acetone to create a glossy surface, though this comes with practice. Also experiment with other materials like NinjaFlex, BronzeFill, WoodFill and carbon fibre.

Printer used Ultimaker 2
App name ZBrush
Filament used Form Futura
Complexity

Print a multi-use dragon bowl

COMBINE 3D SCULPTURE AND PRODUCT DESIGN WITH THIS DETAILED DRAGON HEAD SNACK BOWL

In this tutorial you will learn to create a support-free design with two different functions: a small bowl for chocolate, fruit, etc. or a hanger for your clothes.

The project will focus on 3D sculpting in ZBrush, apart from the screw holder mechanism that will be downloaded from the MyMiniFactory site and then imported into the model.

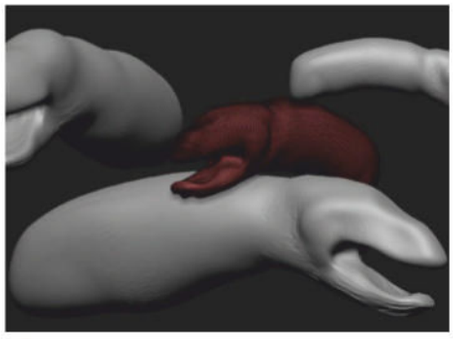
When you are designing an object to be printed, especially something that is to be used, there is a series of tasks that you work through to get the desired result. We'll start by searching for reference images of a dragon online in order to plan the primary forms. Reference images are incredibly useful for whatever you are modelling, especially for items that are based on real things.

You'll see how we fix the volume of the object after having explored the final design that will be produced, how we add secondary forms, how we keep a flat and clean base to add some contrast between the detailed part of the concept and the product idea of it, and how to add details and fix some proportions.

Finally, we will reveal how to optimise for 3D printing without supports. After seeing how we put this product together, you will be able to experiment with your own designs.

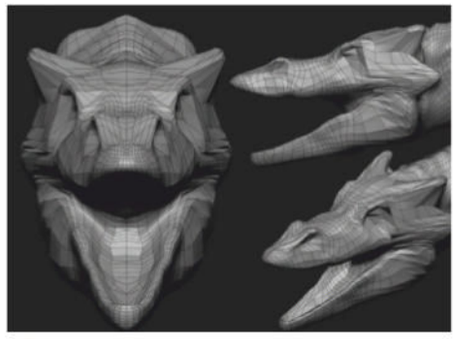
Maker: Francesco Orru is a 3D character artist studying for an MA in Computer Animation at Kingston University. In another galaxy, within *Starcraft*, he is known as Fisherman Sardinian

Profile: myminifactory.com/users/4theswarm



01 ADD DYNAMESH SPHERE

Grab a Dynameshed sphere from the Lightbox menu. With the Symmetry button activated and with the Move brush set to a large draw size, you need to push and pull out and modify the sphere shape. Use a good reference image to accurately draw out the general shapes of a dragon's head.



02 ZREMESH AND MOVE

Once you have your sphere sorted, Zremesh the rough geometry in order to re-structure the polygon topology. Gradually develop the sphere by using the Move brush and Clay Build Up to get a silhouette of the dragon's head. Remember to work with a lower polygon count to start with.

03 SCULPT PRIMARY FORMS

You now need to sculpt a 3D-looking V – this will be the primary form for the dragon head – and a flat circular base for the bowl. Use your reference images to plan these. Use Clay Tube, Build Up or the normal Clay brush to add volume to the primary forms, and use Dam Standard for carving into the model.

04 PLAN THE PRODUCT

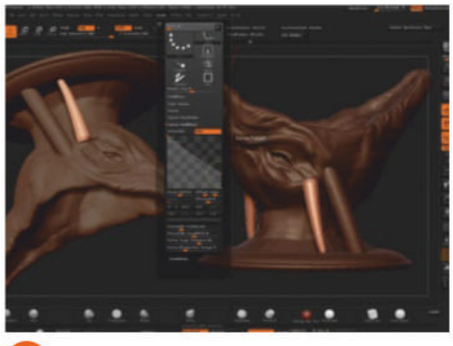
Our initial plan was to convert a flower vase into a snack bowl. The idea of a dragon's head with its jaws wide open seemed like a great visual impact; using the head of a dragon and filling it with sweets and snacks adds to the juxtaposition. However, the teeth could become coat hooks if wall-mounted...

05 EXPLORE THE DESIGN

Create a flat base as an external subtool, then merge it with the dragon head form. To get a compact design, remove the vase with the Select Rectangle: holding Alt, delete the middle and move the head to the base. Use the Selection tool instead of a Trim Curve so you can quickly undo or correct selections.

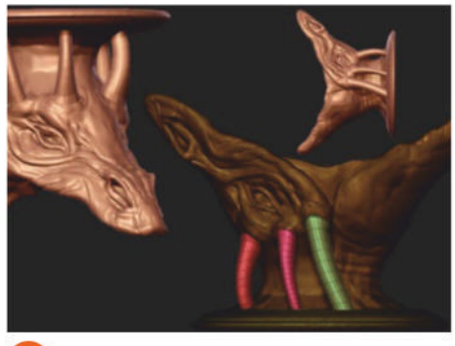
06 FIX PRIMARY SHAPES

Next, block out the general shapes and start adding volume and definition to the jaw and eye areas. Use Form Soft and Clay Tube to add volume to the surface in combination with Dam Standard, Trim Dynamic and the Move tool. Use Backface Masking to work on just one side; this helps when defining teeth.



07 ADD THE HORNS

Add horns using the Curve Tube brush so you can experiment with curve shapes as you draw the lines. Adjust the shape of the curves with the subpalette under the Stroke menu – keep Intensity off and Size on. You can invert the two default dots of the small canvas to quickly get the exact curvy mesh.



08 SPLIT IN POLYGROUPS

Split a new polygroup to sculpt independent pieces if you want to Zremesh and work with a better topology on certain parts. Organise your sculpt in different areas to focus on each subtool and speed up the processing of heavy operations. Orient the sculpt around 45 degrees to ensure a support-free print.

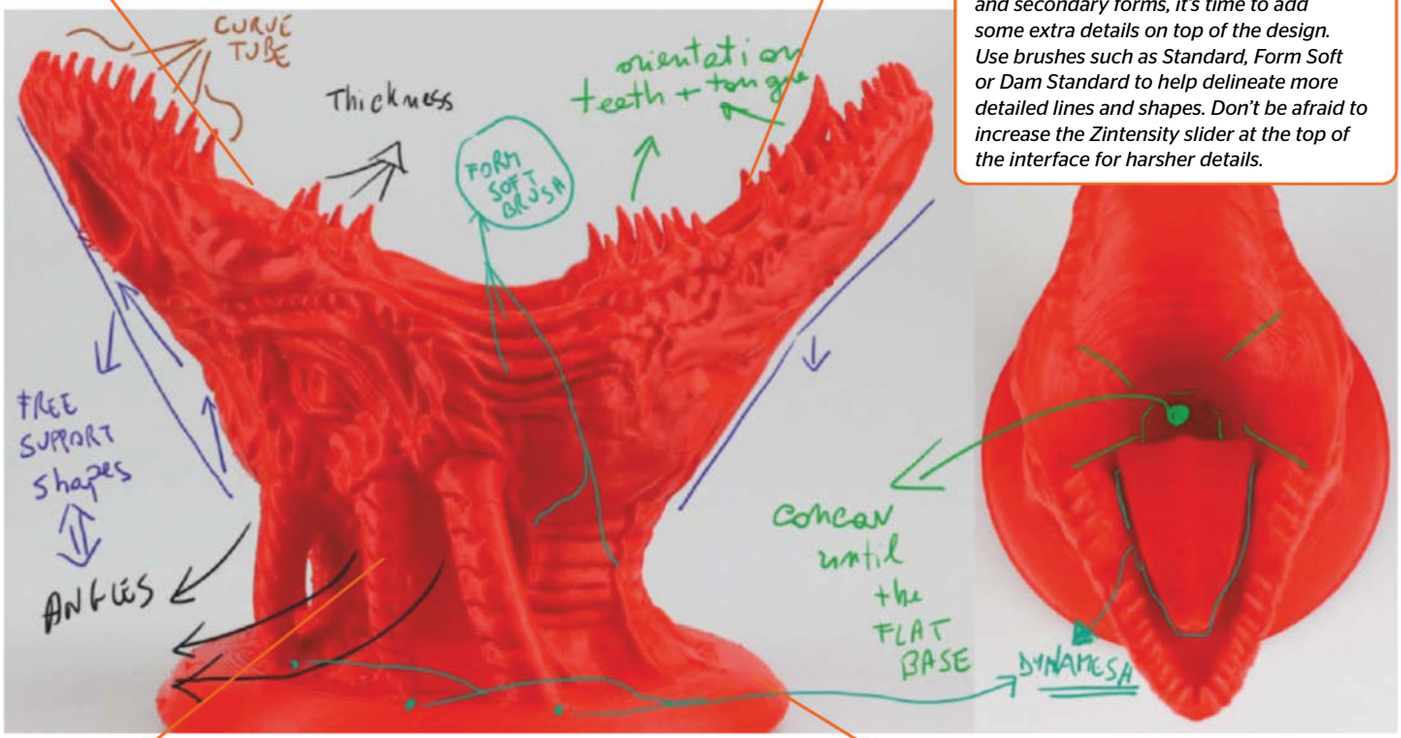
09 DEFINE MORE FORMS

Now define the secondary forms. Mark the transition between the upper part and the jaw to add realism, and create bumps and skin effects. Add teeth with Curve Tube, using Symmetry, Duplicate Subtools and Transpose Line in Move, Scale or Rotate mode to find the best look for both rows of teeth.

GETTING SUPPORT-FREE MODELS

The thickness of different subtools like the teeth, tongue and horns needs to be adapted to be proportionally scaled for the dimensions of our final product

Ensure you have a good orientation of some of the shapes that will be pulled out from the main body, such as the dragon's teeth and tongue

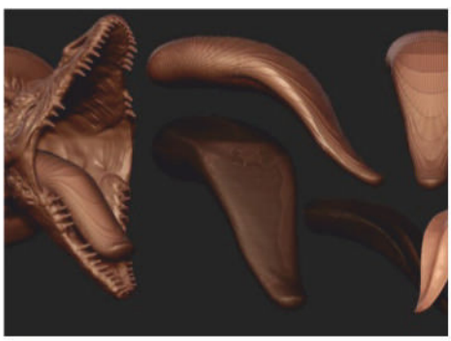


DETAILING FOR 3D PRINTING

Once you have finished with the primary and secondary forms, it's time to add some extra details on top of the design. Use brushes such as Standard, Form Soft or Dam Standard to help delineate more detailed lines and shapes. Don't be afraid to increase the Zintensity slider at the top of the interface for harsher details.

For a support-free design, focus on sculpting angles that are at least 45 degrees because this will ensure that the printer will not have to generate support structures. This is less time consuming, as you will have less to remove, and keeps the detail intact

Consider the material that is unnecessary to your design and then cut it from the model – the base, for example, doesn't need to be overly deep and this can save you filament

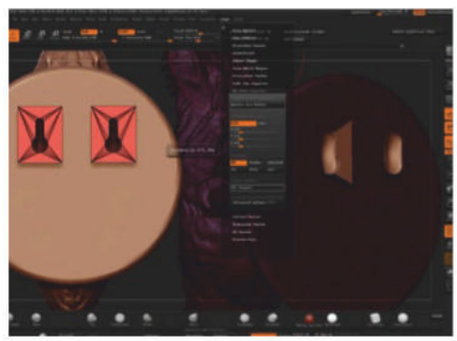


10 ADD THE TONGUE

To sculpt the tongue and add it onto the design, insert a sphere, adjust the volume with Trim Dynamic and Clay brushes in Dynamesh mode. Create more surface variations with Form Soft, holding Alt on the top polygons, and Dam Standard in order to complete the basic tongue design.

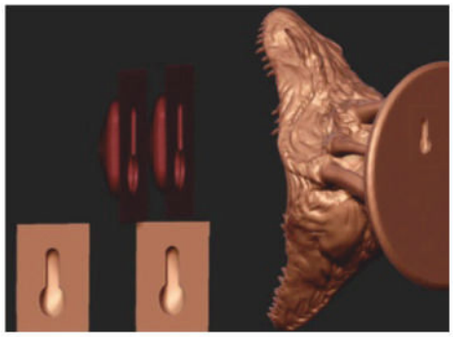
11 CREATE THE EYES

All the main components of your design should now be created, apart from the eyes. In Symmetry mode, place two small spheres for the eyes, move them with the Transpose line and sculpt cavities for the pupils using the standard brush in Subtractive mode with a Drag Rectangle Stroke and Alpha 06.



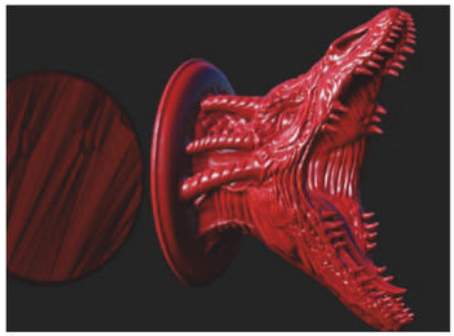
12 IMPORT SCREW HOLDER

You should have all the parts for your bowl/coat hook design. Download the screw hole geometry from **MyMiniFactory.com**, import the file into ZBrush and orientate the screw holes in the bottom of the base. Use Merging then Dynamesh all of the groups together. The dragon head can now be wall-mounted.



13 DYNAMESH HOLDER

These last steps are simple. Add two cubes with the same proportions as the screw hole STL, then Dynamesh them, merge them together with the dragon base in Subtractive mode and re-apply the Dynamesh again in order to add the two cubic cavities to the back of the flat base.



14 FINISH THE MODEL

Final step: now use Decimation Master to decrease the number of the polygon target below 500k for a good decimation, reducing the polygon count but preserving detail. Now click on the 3D Print Exporter plug-in, save the model and send your geometry to Netfabb for scaling and slicing in MakerWare.

15 MOUNT THE DRAGON

When designing the dragon bowl a few steps back you inserted two spaces at the back of the model – these spaces are for mounting the dragon head onto a wall, should you wish to use the print as a decorative coat hook. You will just need to purchase two wall mounting screws and some fireproof jackets!

TEST PRINTING IN CURA SLICER

The time for printing depends on options like the Platform Adhesion type, print speed, fill and quality. The Cura estimation time for this project was around 10 hours for a 125g object

Set Layer Height to 0.20 in combination with a Fill Density of 10%. Choose no supports and no platform adhesion type, since we don't want any brim or raft

The great thing about Cura, once you have imported your STL, is that the software enables you to customise the printing settings to exactly how you want them. You can change the scale, the quality, layer height, the shell thickness and even customise how you would like to generate support around the model – this is important for optimising the print and the printer's efficiency

LOW POLYGON COUNT MEANS FAST SLICING

It's recommended to keep the geometry polygon count as low as possible because this will greatly reduce the slicing time. To get a low polygon count for slicing, just use the Decimation Master.

Printer used	App name	Filament used	Complexity
MakerBot Replicator 2	Rhino	BronzeFill, WoodFill	●●●○○

Sculpt a mecha rhino

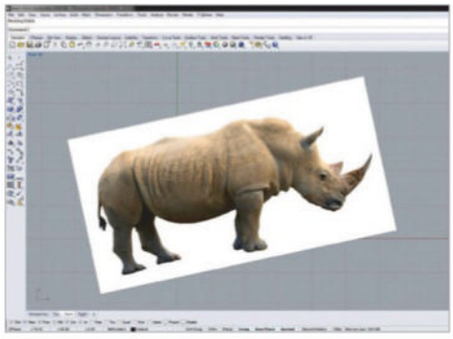
LEARN HOW TO SURFACE MODEL IN RHINO AND MAKE YOUR VERY OWN MECHA-STYLE RHINO HEAD USING BRONZE AND WOOD

It is easy to get so caught up in creating the actual shape of a model that you neglect to consider the surface. With some subjects, it is the surface that holds all of the character, such as textured organic materials or glistening metallic objects. Using this tutorial you will learn how to surface model using Rhino as well as how to print with alternative materials like BronzeFill and WoodFill.

We will be making a mecha-style model of a rhino head, though the techniques that we'll use here can be applied to any model and are a good introduction to the type of surface modelling that is achievable within Rhino. We will be modelling surfaces and creating objects that would be very difficult to make in other programs, while still being specific with measurements and drawing. It is in this way that Rhino could possibly be considered an in-between to ZBrush and SolidWorks.

Maker: Lloyd Roberts is a product designer who has had a passion for 3D printing since buying his first desktop printer in 2012. His designs are as support-free as possible and always optimal for 3D printing

Profile: myminifactory.com/users/lloydroberts93

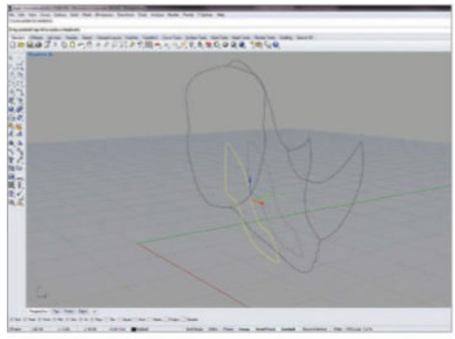


01 FIND A REFERENCE

Before you begin modelling, it can often be a good idea to use a reference image – spend a little time now finding a good one to use. Once you've got one, type in the command Picture Frame to insert a reference image onto your plane, then rotate it until you are happy with its positioning.

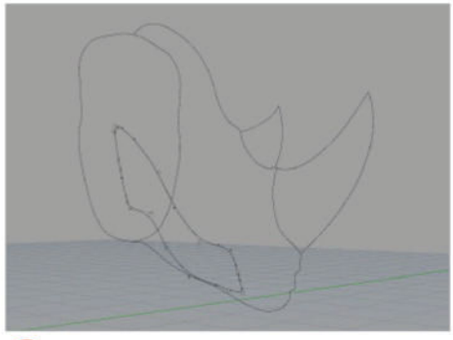
02 TRACE THE IMAGE

Using the Curve tools, located on the left sidebar of the interface, start tracing around the reference image and make a basic outline guide for your model. Repeat these first two steps again using a front view of the rhino so that you will have an outline for both perspectives.



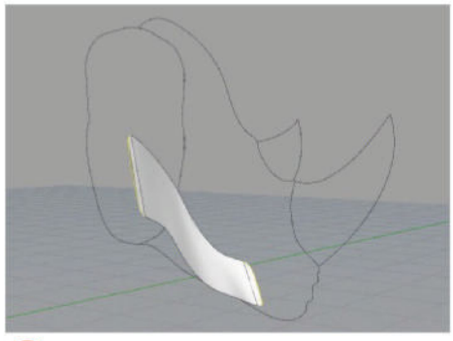
03 DRAW THE FIRST SHAPE

Now that we have our guide curves, we can draw the outline for our first shape. Drawing a shape in any of the 2D viewports will always leave you with a sketch on the current plane in view; to move it out from here you will need to use Gumball to drag it into position.



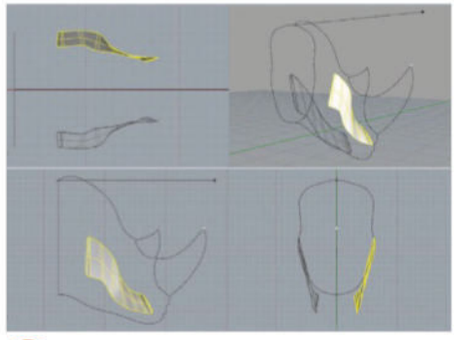
04 DRAW IN 3D

With our 2D curve we can now turn on control points and, again using Gumball, drag each individual node of the curve into different planes to create a free flowing shape. Try to follow the shape of where you imagine the head of the rhino would sit. You can always adjust this line easily later.



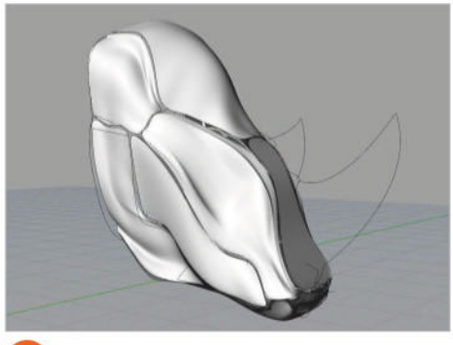
05 MAKE FIRST SURFACE

The next thing that you need to do is Split the line into four pieces using two polylines that cut across the shape. These four lines can then be joined together using the command Sweep 2 to create your first surface. Make sure that you select the lines in the correct order.



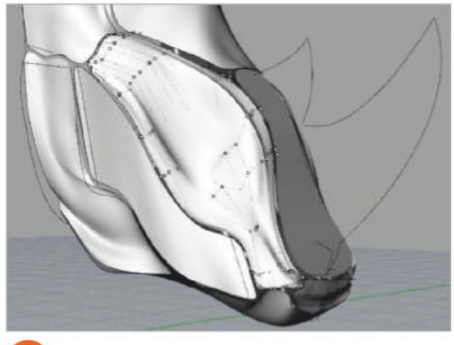
06 MIRROR WITH HISTORY

Next we shall use the Mirror command to make the object symmetrical. Before doing this, it is good practice to turn on the Record History tool. This means that any changes we now decide to make to our object on one side will automatically be updated on the mirrored surface as well.



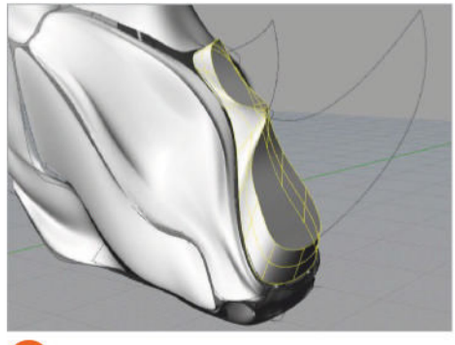
07 REPEAT STEPS

Repeat steps 3-5 for each surface until you are happy with all of your surfaces and the look of your object as a whole. At this stage it is easy to go back and change any shapes that you are not happy with, or to experiment with making new ones, so feel free to try out other reference images.



08 MAKE EVERYTHING FIT

Once you have your surface, you can now turn on the control points for them individually. This enables you to move points to further develop your shape or to position them closer together or further apart at specific sections, as opposed to editing the entire shape.



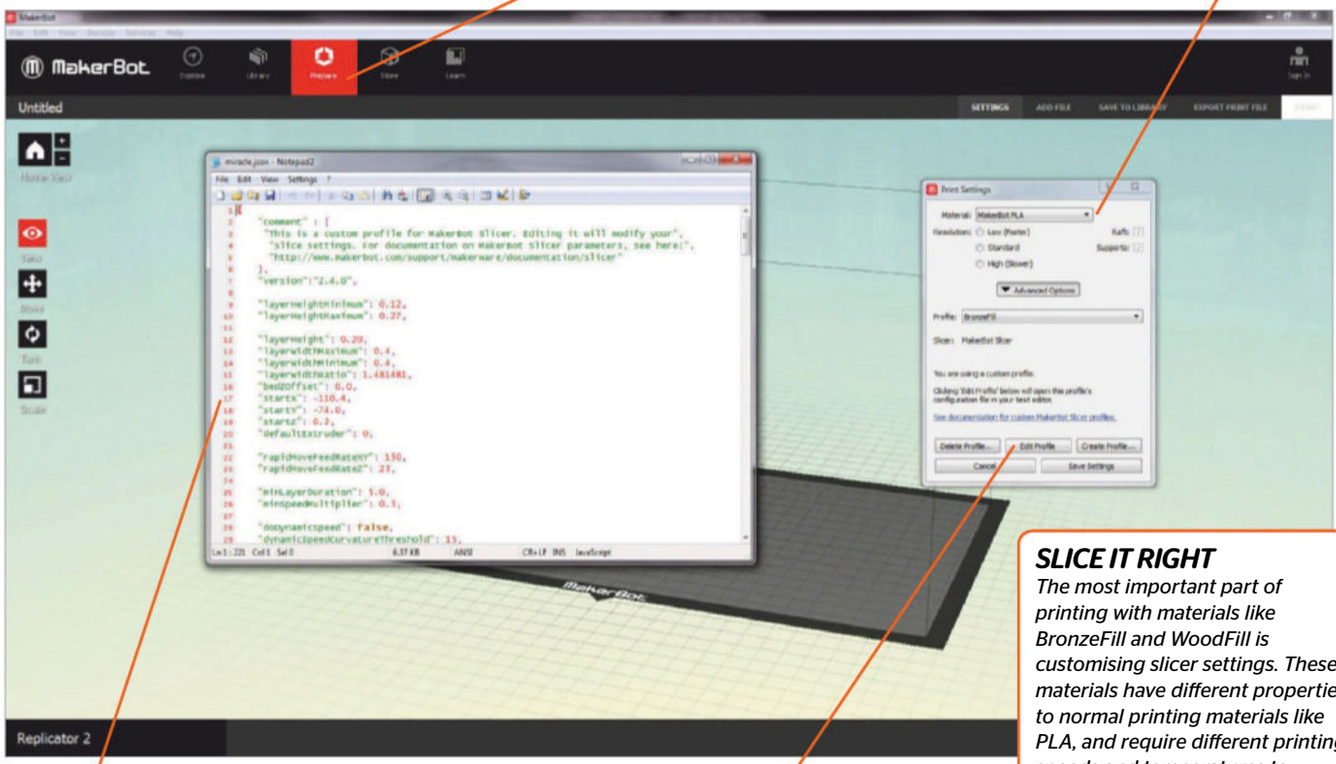
09 LOFT THE SHAPES

The next tool we are going to use is called Loft, which defines a surface shape by fitting it through selected profile curves. Using a profile curve of our top shape and the curve used to create the existing surface, Loft them together to create a new 3D surface and then Join them for a solid object.

SETTING UP A SLICING PROFILE

From this menu inside the MakerBot software you can import your 3D files, open the print settings window, save your files and export them to print

At the top of the window you can select your printing material to change simple settings like layer resolution and printing temperatures

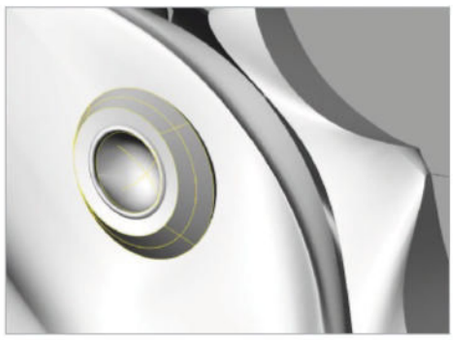


Edit this like a normal text document, using 'false' and 'true' to toggle options like support material, whilst using decimals to specify details like layer resolution

If you want to edit more settings within a slicing profile, this is the button you need. It will open up a second window showing general information you can edit

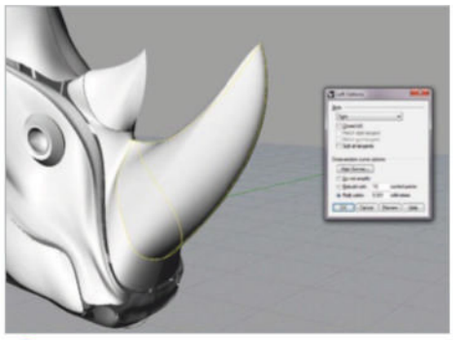
SLICE IT RIGHT

The most important part of printing with materials like BronzeFill and WoodFill is customising slicer settings. These materials have different properties to normal printing materials like PLA, and require different printing speeds and temperatures to optimise them. Suggested settings are 40-100 mm/s and 195-200˚C. Experiment with them slightly to match your specific machine, and edit other settings like retraction and fan speeds as needed.



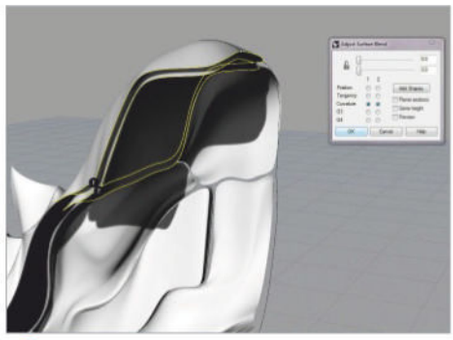
10 ADD THE EYES

Using the same tools as before, now draw two oval shapes to form the eyes, offset from each other, then Loft them together to create your surfaces. Then using BlendSrf, join your lofted shape to one half of an Ellipsoid, which you will need to Split in the same way as our previous lines.



11 DRAW THE HORNS

The horns can then be built by drawing three lines and using the Loft command again. By splitting the top profile curve that we used to create our previous shape, which the horns protrude from, we can have a very accurate and seamless shape that will flow together well.



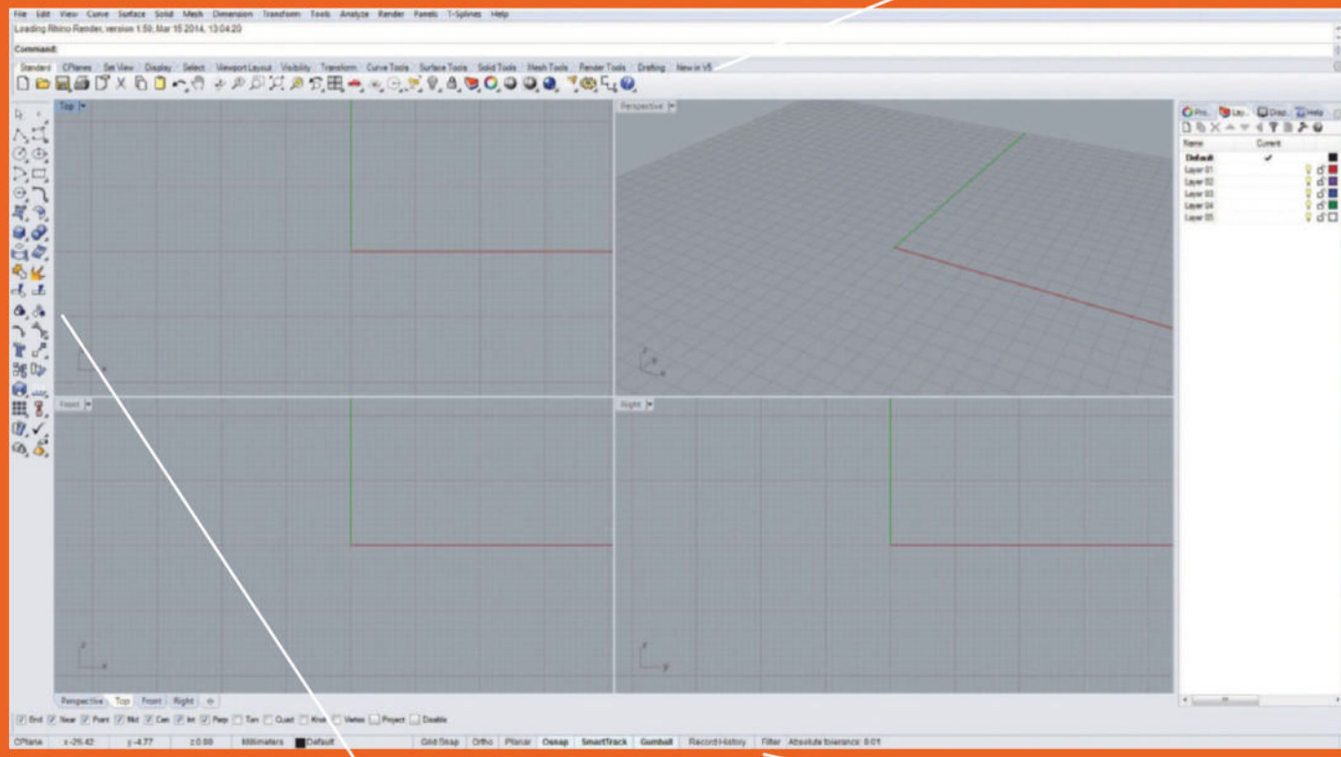
12 MAKE SOME SOLIDS

Now that we have our model looking like a rhino, it's time to add thickness to the surfaces to begin making a 3D-printable object. Use OffsetSrf to offset the surfaces into solid objects, or instead offset the surface without making a solid object and then use BlendSrf to join them together.

MASTER THE RHINO INTERFACE

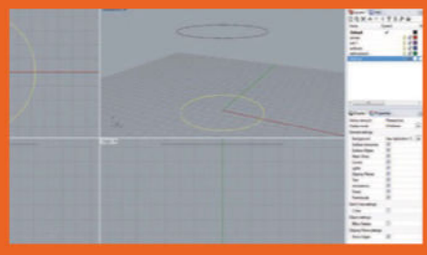
If you are completely new to Rhino as a 3D modelling software, it is a good idea to first familiarise yourself with the interface. The main screen is made up of four viewports; usually these are top, front, right and perspective, though you can click on these titles and change them to show a much larger range of different view types. Usually it is helpful to model using all four of these windows together, drawing curves in any of the 2D ports whilst executing surface modelling commands in the perspective view.
It is also helpful to use different shaded and wireframe viewports so that you can see what your model looks like as a solid object, as well as be able to use curves and edges all throughout your objects.

Usefully, the tools along the top are grouped together under different tabs to help you find what you need

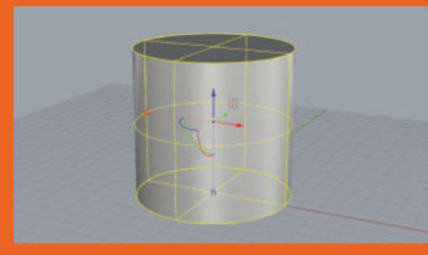


Down the left-hand side of the screen are the majority of tools that you would most likely use, including the basic 2D drawing tools and more complex surface modelling tools

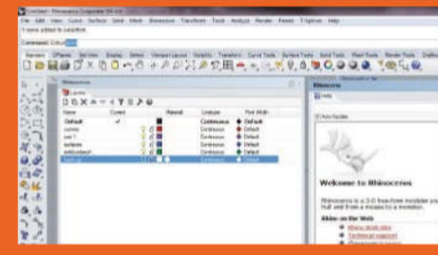
Across the bottom of the screen you also have different snap tabs. These enable you to quickly switch on and off different ways of snapping your tools on the interface



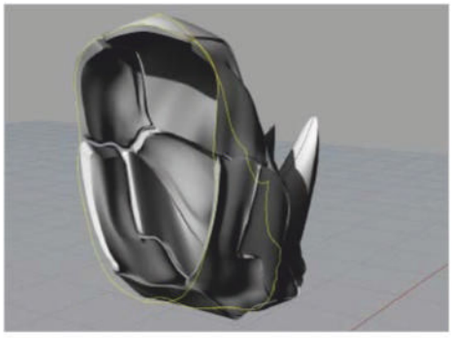
1 The toolbar on the right-hand side has other helpful menus. Layers enable you to separate different objects, curves and imported images, then hide and lock them individually with ease. The help box is also great for explaining tools and their functions if you are stuck or new to the software.



2 The coloured tool in the middle of the cylinder here is known as Gumball. Gumball is an incredibly useful tool that helps you quickly transform an object using scale, move and rotate quickly and in multiple ways, moving objects along a specific axis or scaling with or without uniformity in an object.

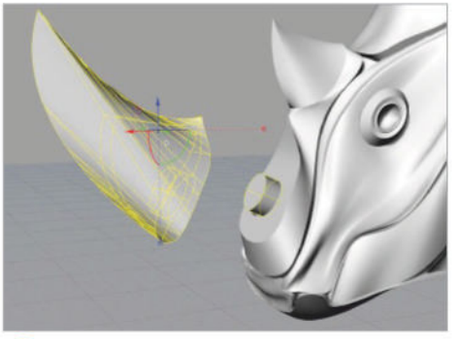


3 Within the Rhino interface, as well as by using the toolbars across the top and the side of the interface, you are able to type in commands using the keyboard. These commands will appear in the command line along the top of the interface and prompt you with other suggestions depending on your entry.



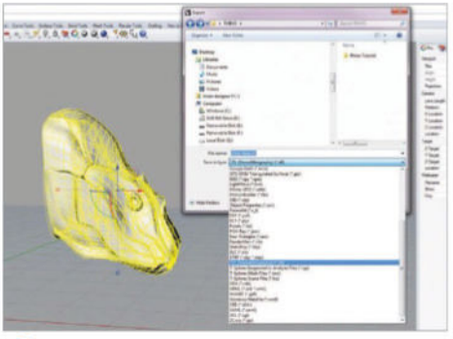
13 SEAL THE SHAPE

The next step is to Rebuild the three curves that we had for our original guide lines in order to create smoother curves that we can loft together. By then moving the control points for this surface, you can fill the gaps between the individual faces to create your solid object.



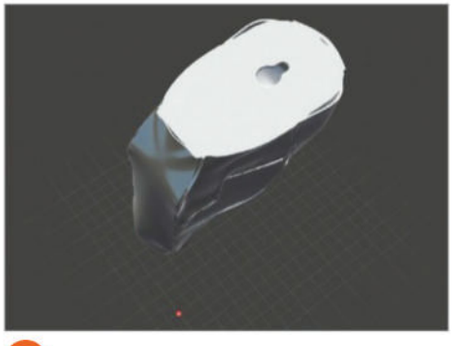
14 MAKE THE JOINS

Now for connecting parts. Extrude a circle between our two objects and offset this surface so we have two objects, one slightly larger to account for printing tolerances. Use BooleanDifference on the larger extrusion to make the female part, then BooleanUnion on the smaller extrusion to make the male part.



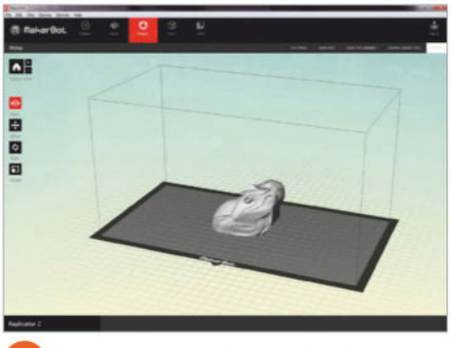
15 COMBINE THE PARTS

Finally, make sure that all of the parts for the head are one component by using BooleanUnion, and then export the horns and the head as three separate STL files. This is so that we can orientate each piece individually and then print them using different materials.



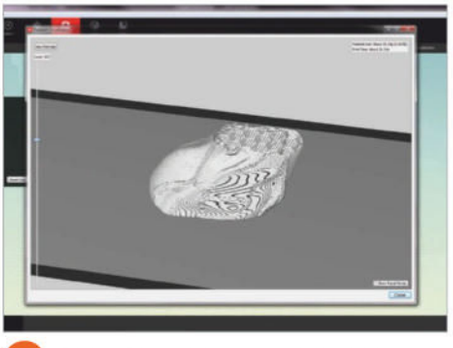
16 USE MESHMIXER

The final (optional) touch before printing is adding a Keyhole Slot so that you can hang it on the wall. Import the object into Meshmixer, along with the Keyhole Slot on **www.myminifactory.com**, tagged under Functional Add-Ons. Position them together and use Boolean Union to combine them.



17 SLICE THE OBJECTS

Using your preferred software, you can now slice your model so that it is ready for 3D printing. Import your objects and then orientate them to make them optimal for printing. Change the settings so that they are specific to the material that you have decided to use and then click Export.

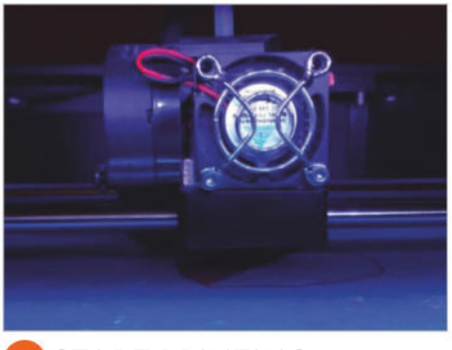


18 CHECK THE PREVIEW

In your preferred slicing software, you can now preview your object and see exactly how it is going to printed. Using the slide bar on the side you can view each individual layer of your model and identify any issues you may have. Go through each slice in turn now and then fix any issues you notice.

19 PREPARE THE PRINTER

Once you are happy with your finished model and before you start printing, ensure that your build plate is level, prepped and that you have enough material on your spool of filament. Also make sure that it is loaded correctly and that there are no tangles in your spool.



20 START PRINTING

Whilst printing in materials such as BronzeFill and WoodFill, it is a good idea to keep a close eye on them. You shouldn't usually run into problems when printing if your settings are correct, but if you do come across any tangling or a blockage, these materials can be more troublesome than PLA and ABS.

21 FINISH YOUR RHINO

Post-printing, you can now polish your object and fix the individual components together using the male and female joints, and possibly some glue. Check out the opposite page to see how we finished ours. With that done, your mecha rhino is finished and ready for hanging up on the wall!

FINISHING THE BRONZEFILL

Antique Patina is a liquid finish you can paint onto your model before buffing and polishing

Use a test print of your bronzefill model to practice your finishing techniques on, so that you don't ruin your finished model

The Patina is applied by brush onto the pre-buffed and polished model. The model is then buffed and polished again afterwards for the final touch

USE TAPE

Using tape on your build plate will enable your printed objects to be firmly secured and also easily removable post-print. One trick that you can try to apply is using glue underneath the tape to further minimise warping, by stopping the tape itself from peeling away from the plate.

Add style to your finished prints

YOU'VE GOT YOUR 3D PRINT ALL READY, SO WHAT NOW? DISCOVER HOW TO TAKE THEM FROM PLASTIC TO FANTASTIC WITH THESE AMAZING FINISHING TECHNIQUES

Want to print a museum-quality dinosaur skull but just realised that you only have neon green filament left? No need to fret – it doesn't necessarily mean that you have to put your creative vision on hold. It just means that you need to get a little bit more inventive with your finishing techniques, and with these tips and tutorials from MyMiniFactory's very own post-processing team, who have years of experience in painting and finishing prints to a high standard, enhancing the finish of 3D prints has never been easier.

We are going to reveal the professional tricks for creating metal effects for cosplay weapons, stone effects for sculptures, furry effects for cute creatures and much, much more. No background in model making or fine art is required; anyone can get involved.

Most of these effects can be used on both PLA and ABS prints and all materials used can be found in good DIY and art shops.

Makers: Together, Catherine Wood, Pallavi Davé and Sarah Wade form iMakr's professional finishing team. They bring creativity and realism to prints by innovatively applying their crafting skills

Profile: www.myminifactory.com/users/Catherine_W
Profile: www.myminifactory.com/users/Pallavi
Profile: www.myminifactory.com/users/Candlegirl3

METALLIC AND BONE FINISHES

01 PRIME THE BASE

We are going to combine bone and metallic effects for a Pteranodon skull and its base. First up is the base, which is going to be made to look as though it is metallic just by using some paint. Begin by priming the base with a single coat of black acrylic primer.

02 PAINT A BASE COAT

Once that's dried, paint on a base coat of brass metallic paint. Apply two coats if necessary because this will ensure that the colour of the filament doesn't show through the paint, which will help lead to a more realistic effect overall.

03 ADD A BLACK WASH

When you are happy with the coverage of the metallic paint, apply a black wash over everything; a thin, diluted mix that will dry to emphasise shadows. This will go into the grooves of the print and help reinforce the feeling of depth.

04 ADD HIGHLIGHTS

The black wash in the previous step added depth and shadows, which needs to be balanced by emphasising the highlights. Do this by applying gilding wax to the ridges and raised areas of the model. Not only does this create highlights, it also brings out detail.

05 FINISH THE SKULL

With the base sorted, it's time to add a bone finish to the skull so that its ready to be mounted. Begin by sanding the skull using 600-grit sandpaper. This will make the surface nice and smooth, which will add to the final bone effect.

06 SCORE THE GRAIN

We'll now add some authenticity to our skull. Using a wax carving tool, carefully score lines into the print in the direction that the grain would naturally appear on the bone. If you aren't sure how this looks, do a quick Internet search for a few reference images.

07 PAINT THE SKULL

With the surface preparation out of the way, paint over the print with two coats of white acrylic primer. Once that has finished drying, paint on a cream base coat. A mixture of white and yellow ochre will create a nice, natural bone colour.

08 ADD A BROWN WASH

Coat the entire model with a brown acrylic wash. This will seep into all the cracks and grooves, bringing out the textures and organic details. Apply a second coat of wash to add to this effect, giving the organic texture greater depth.

09 FINAL ASSEMBLY

Once the skull and the base are completely dry, glue all of the parts together and seal the entire model with a matt sealant. This will ensure that the paint adheres to the model much better, and it will also give you a longer-lasting finish.

SMOOTH ABS OBJECTS

01 HIDE THE LAYERS

To remove the lined appearance of the layers in an object, you can steam your ABS print in an acetone bath. You' don't need specialised equipment – a rice cooker is just the job.

02 SET UP THE COOKER

Pour acetone into the rice cooker, 0.5 cm deep. Put the print on a platform 3 cm high. Ensure the print doesn't touch the acetone. Switch on and wait for condensation to form.

03 STAND AND REPEAT

Turn off after 1-5 minutes (depending on print size) and remove the lid without dripping on your model. Let it stand in the cooker until the molten layer sets. Repeat until smooth.

WOOD EFFECT

01 PAINT ON GRAIN

Prime the print with acrylic primer then apply a medium-brown base coat. Paint wood grain lines onto the print in a lighter shade of brown and blend with a damp paintbrush.

02 APPLY VARNISH

Once dry, paint in any extra detail you want and leave to dry. After that, use a thin coat of dark brown wood varnish and apply to the entire print. Repeat as necessary.

03 PUT TOGETHER

With the varnish applied, leave it to dry in a dust-free environment. Once it is completely dry, you get to the fun part of assembling all the pieces to reveal the final product.

FLOCK EFFECT

01 PREP THE OBJECT

Spend some time masking off the sections of the model that aren't to be flocked. It pays to take your time with this. Once you're done, cover the rest in flocking glue or PVA.

02 APPLY THE FLOCK

Using a sieve, apply flocking powder onto the model. Ensure you have a nice, even coat and then leave to dry. Dust away the excess flocking powder using a soft paintbrush.

03 ADD DETAILS

Remove any masking tape or fluid you applied and then paint on the fine details using acrylic paints. Seal the painted areas with clear nail polish.

FROM SHINY COPPER TO VERDIGRIS

Mix copper powder and PVA glue (two parts powder to one part glue) to form a paste and apply this to the entire print

Paint a solution of salt (1 tsp) and vinegar (1 tbsp) onto the entire model using a paintbrush. Leave the model in a container until the desired effect has been achieved

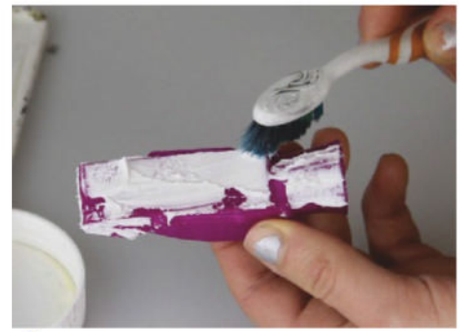
PREPARING THE PRINTS

Preparation is key when finishing prints – do not skip this part! Before beginning with any of the effects explored here, remove all the support material and key the print using 400-grit sandpaper. Wipe the print with a damp cloth to remove dust and grease. Now the print is ready for finishing.

Once dry, polish the surface using 600-grit sandpaper followed by steel wool to bring out the shine

Gently wash off the residue and dry thoroughly. Seal with a matt sealant to protect the finish

STONE EFFECT



01 BUILD UP FORM

Apply filler or modelling paste to the whole of your model in an uneven layer using a palette knife. Work into the paste using a toothbrush and paintbrush to create varying surface textures. Once it's dry, sand down any sharp points.

02 ADD PAINT

Paint over the textured paste with a grey primer, then apply a second layer of paint in varying shades of grey to add tone and depth to your print. After this you can use a black wash to emphasise the grooves. Use a reference image to help you create a realistic stone effect.

03 ADD HIGHLIGHTS

Sponge on white acrylic paint to highlight the ridges and details. This will create greater contrast on the model and add to the overall stone effect. Next, spray with matt sealant to protect the paintwork. This also makes it last considerably longer and increases durability.

Printer used	App name	Filament used	Complexity
Ultimaker 2	ZBrush 4R6, Rhino, 3ds Max	PLA	●●●●●

Masks are a fantastic way of learning a raft of essential modelling techniques, especially when it comes to mastering the art of surfaces. In this example, the aim is to create a hard surface-looking wearable mask. This project will give you the opportunity to learn new software and techniques, it will expand your design skills and open up a whole new world of 3D design. Perhaps the most important lesson to take away is how learning to design a functional 3D printing model is the ultimate skill to attain.

In this tutorial we will use three different pieces of modelling software, namely ZBrush, 3ds Max and Rhino. Over the course of the steps, you will learn how to sculpt shapes using a template from ZBrush and import a base mesh into 3ds Max for hard surface modelling. The style you are aiming for is hard surface, mechanical modelling – from there you will learn to import into Rhino and prepare the models to be sliced for 3D printing.

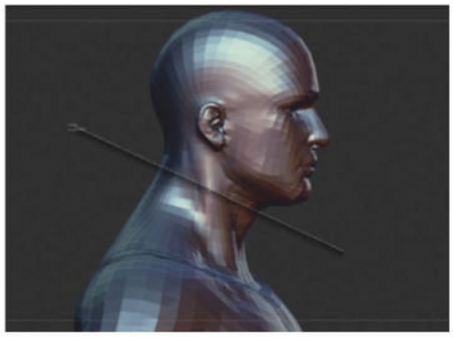
We'll be honest right from the start – this tutorial is not for the faint-hearted! It will require patience and time. However, by the end you will have the skills to be able to use three different programs to create a wearable, functioning 3D-printed design.

Maker: Stefanos Anagnostopolous studied 3D animation and multimedia production. He takes inspiration from movies and games

Profile: myminifactory.com/users/Stefanos

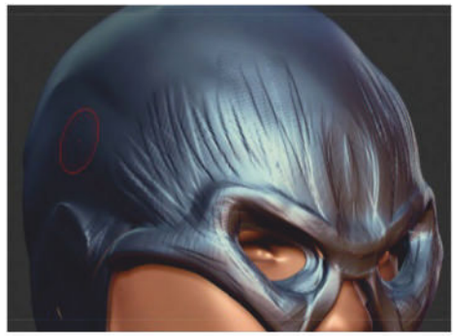
Construct a sci-fi mask

TAKE YOUR 3D MODELLING TO THE NEXT LEVEL WITH THIS IN-DEPTH GUIDE TO DESIGNING A 3D-PRINTED, WEARABLE SCI-FI MASK



01 SHAPE IN ZBRUSH

Open the Lightbox palette in Zbrush, then go to Tools>Zsketch Facial Anatomy. Delete all subtools and keep only the skull. Use Move and Clay Buildup to push and pull the geometry into a basic helmet shape. Start at the lowest subdivision to get the basic look, then increase to subdivision 3 to add detail.



02 ADD MORE DETAILS

For a sharper effect on the eye socket, use Trim Dynamic. Once happy with the general shape of the sculpt, Zremesh the model up to 33,000 polygons then subdivide up to level 6. Drop back down to subdivision 4 to make it easier to add more detail to the model, such as the side of the cheek bone.

03 ADD ENGRAVED DETAIL

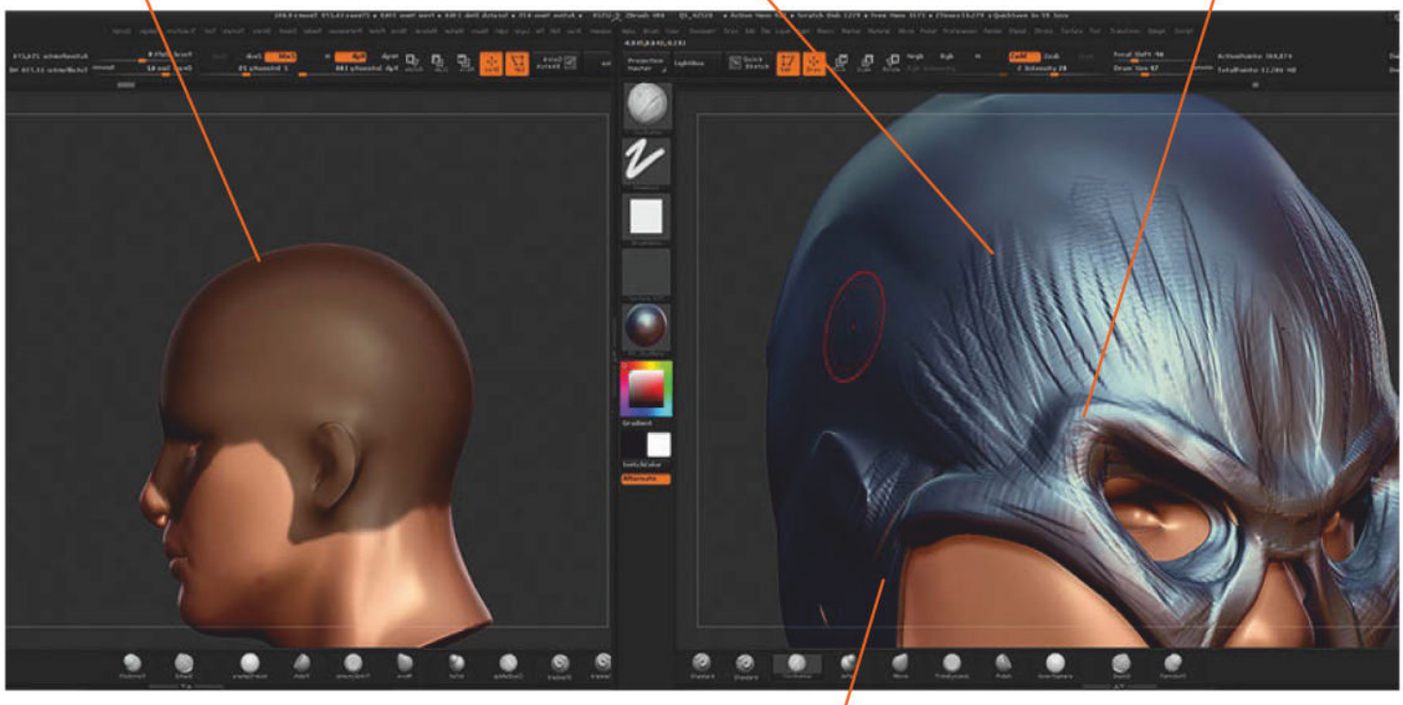
Start adding the engraved detail using the Slash 3 brush, which helps to create the hard surface look of the mask. The engraved lines will give you a guide line for sculpting hard surfaces when modelling in 3ds Max. You may have to go over the lines more than once to achieve the desired effect.

MASKING AND CLAY BUILDUP IN ZBRUSH

Use the Mask tool to build the desired shape over the head template, then use Extract in the subtool palette to create a thickness. Click Accept to create a separate subtool (make sure you are on the Mask subtool)

Now use Clay Buildup to start shaping and building up defined surfaces

Be sure to draw the mask so that it fits the curvature and ergonomics of the head – you don't want an uncomfortable helmet!



USING THE WACOM PEN

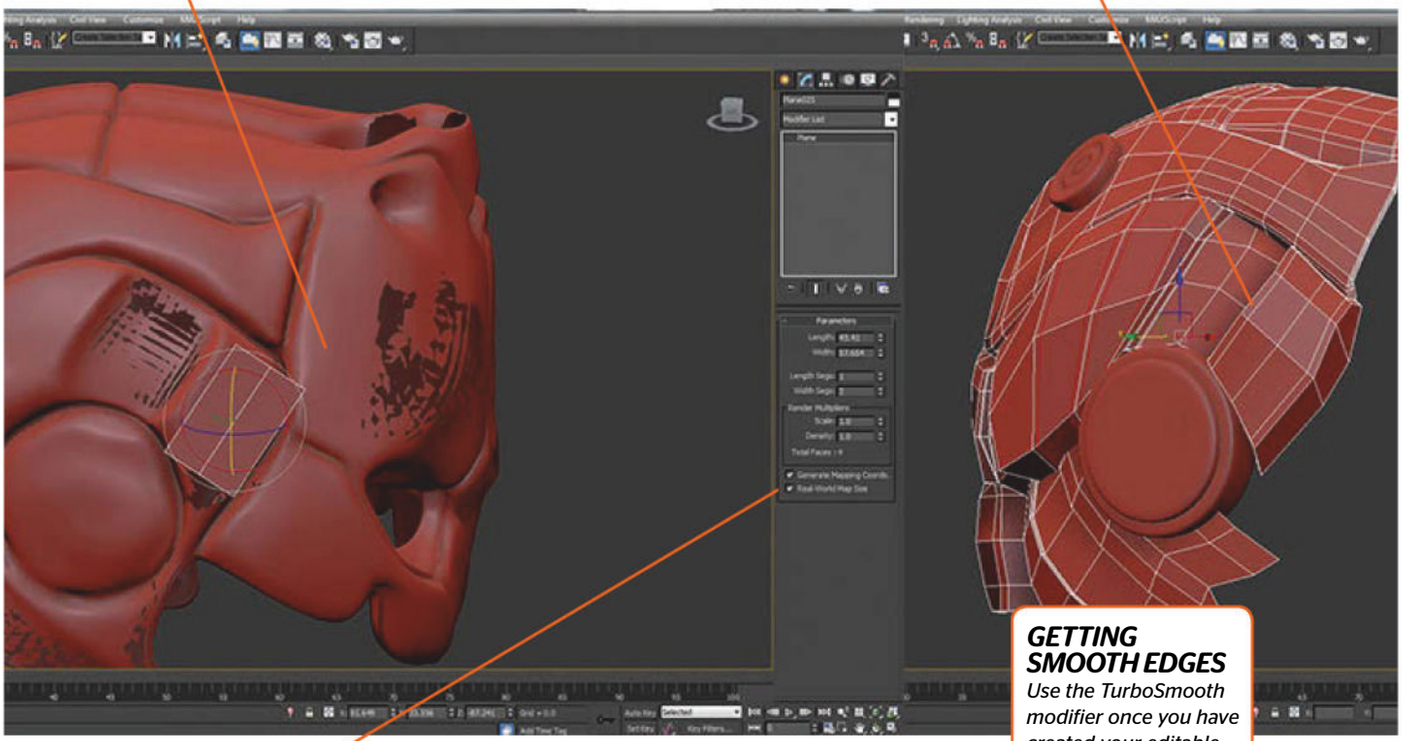
Use light hand movements when brushing. Press softly for light detail and increase pressure on a tablet for harder, more inflated detail. Getting comfortable using a Wacom pen is important – the pen is very responsive, and getting deeper or lighter details can be achieved by simply pressing harder or softer.

Don't worry about scaling the mask until the end of the tutorial; this can be done in the slicing software, as ZBrush is not accurate for dimensioning. Just make sure the shape of the helmet fits a general shape of the head

CREATING PLANES IN 3DS MAX

Open the palette in Standard Primitives under the Geometry button, select the plane you want to start editing and start experimenting with pushing and pulling the shape into the form you require

Create an editable poly. You can edit poly surfaces by clicking on the edge and then pushing/pulling the square into the ruined shape. Play around and use your ZBrush model as a reference for the part you are making



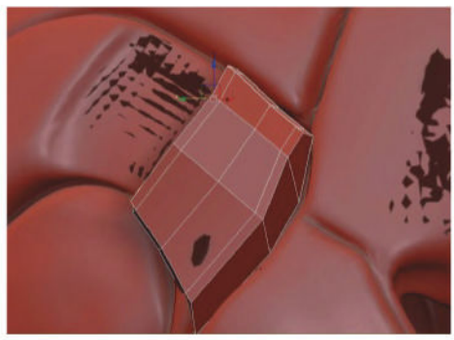
The Real-World Map Size option controls the scaling method that's used for any texture-mapped material that you apply to the mask, using the settings in the material's Coordinates rollout in order to do this

GETTING SMOOTH EDGES

Use the TurboSmooth modifier once you have created your editable poly surface to get smooth, refined edges. This will enable you to get a cleaner shape for your model overall.

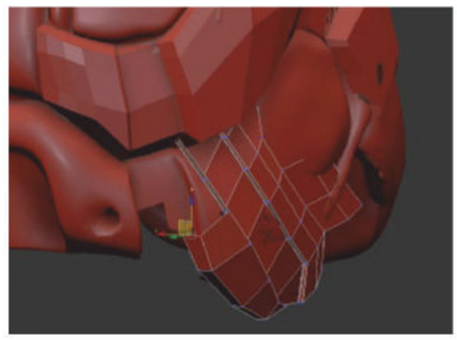
04 FINISH IN ZBRUSH

Going back and forth between brushes means that you can re-define some of the details to look more aesthetic and get as close to your reference image as possible. Once you are ready to export to 3ds Max you will need to Zremesh again so you can import the model as an OBJ file.



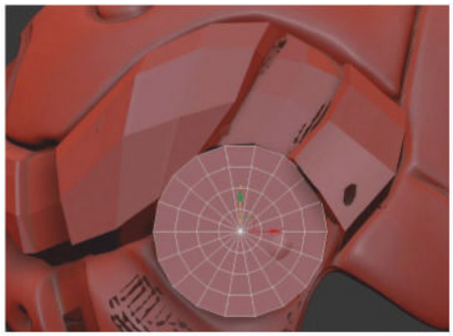
05 IMPORT TO 3DS MAX

Import the Zmeshed OBJ into 3ds Max, then orientate to the left side of the helmet. Make a plane and reduce the edges, open the Modifier palette and use Edit Poly. Increase the number of polygons and manipulate the plane into the shape you require. Repeat this for the front, back and other sides.



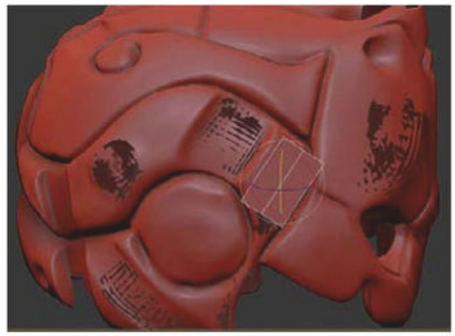
06 MANIPULATE PLANES

Continue to repeat the Edit Poly process by first creating a plane on the desired part of the head. Copy your references as accurately as possible; manipulating planes into shapes requires a bit of trial and error. For example, to model the eye you must edit the edges more than once and split lines for clean edges.



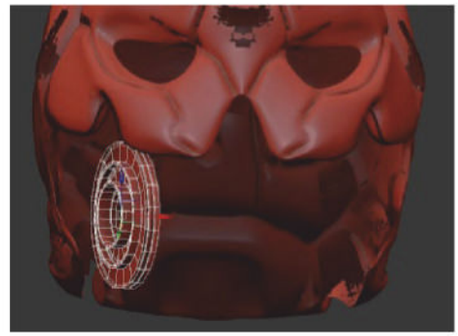
07 EXTRUDE CHEEK BONES

Complete both sides then add a cylinder to one, orientated and scaled accordingly; you will extrude the cheek bones here. Draw a curved line for the bone with Shapes>Line, click Modifier, pick the line and click Vertices to position it accurately to the head. Extrude by editing Weight and Length in Rendering.



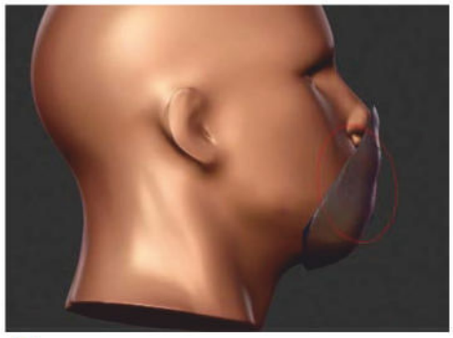
08 FINISH THE HEAD

Continue using the Plane tool for the rest of the head, using editable poly and following the engraved lines sculpted in ZBrush as a reference to create the hard surface effect. By using the model and other reference images, you will be able to re-create the surfaces you will need in 3ds Max.



09 SCULPT BOTTOM JAW

Add a cylinder for the bottom half of the jaw. Ensure you are in the left side view, as it makes scaling and orienting the cylinder easier. Use Modifier>Editable Poly to select the polygons you will need to detach as separate objects; find this in Edit Geometry. Use Modifier>Shell for the hard surface effect.

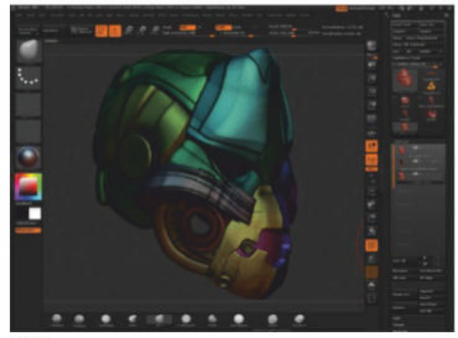


10 IMPORT TO ZBRUSH

Open the original mesh in ZBrush. Mask the bottom jaw from the original mesh template, extract this then use Move and Smooth to clean up the masked part. Subdivide the extract subtool then work on the shape with Clay Buildup. Next, Zremesh to get a clean mesh topology and import back to 3ds Max.

11 IMPORT TO 3DS MAX

Back in 3ds Max, you should now have the left side of the model complete. To create the other half, every subtool that was created will need to have the Symmetry modifier. To join all the subtool parts together, you collapse all the modifiers together by left-clicking on the Modifier box and pressing Collapse.



12 FINISH IN 3DS MAX

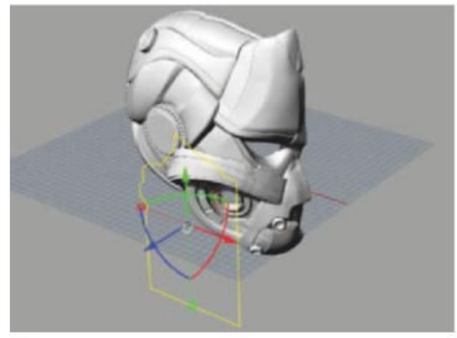
Add the Shell and TurboSmooth modifier to each part. The Shell modifier adds thickness to the parts and TurboSmooth creates a much smoother finish – remember to use two to three subdivisions in TurboSmooth. Once that's done, export everything to ZBrush as one object.

13 OPEN IN ZBRUSH AGAIN

In ZBrush, the parts are together but joined as a solid object. Dynamesh at high-res then decimate the model (Decimation Current, in the Z plugin), using the pre-process mode first. In pre-process you will see an indicator of what percentage to decimate depending on the polygon count.

14 PRINT A TEST PIECE

Now test-print a scaled version and start working out how to cut up the mask into smart pieces. By test printing a mini version of the full-size object, you can use it as a tool to gauge the scale, ergonomics and the split lines for where you will need to slice the full-size version.

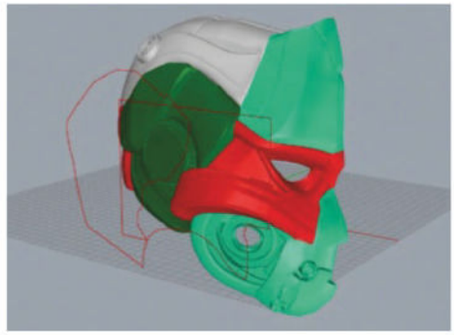


15 EXPORT TO RHINO

Next you will need to import the finished STL file from ZBrush into Rhino so that you can slice the model into parts. Open up Rhino, click File>Import and open up file browser, select the STL file to import and then click OK. Your sci-fi mask model should now load into Rhino.

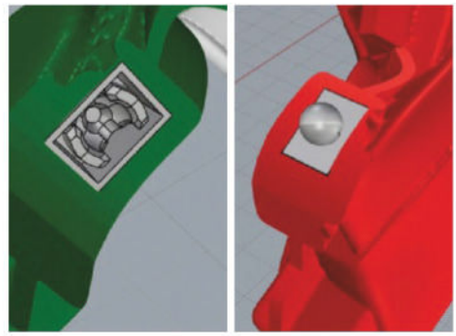
THE IMPORTANCE OF REFERENCE IMAGES.

Before you start any CAD project it is crucial to have a clear idea of how the final model will look, so planning and the careful selection of images to inspire creativity are needed. For this tutorial the inspiration came from the Marvel film *Avengers: Age of Ultron*. The key villain has a distinctive mechanical, hard surface look to the design, and the main idea for the mask came from here. To take the model further, the structure of a gorilla's head was used. Use the Internet to gather images of styles and shapes that will help develop your model, taking bits and pieces that you would like to add to the model. What is important is to gather as many images as possible and start putting together a mood board – this will help with the style and direction that the model will take. Once you are clear with what you want to design, you will need to either sketch out the model that you want to make or find an image online. The reason we use reference images when 3D modelling is to make sure we model accurately! It is very easy to miss details, scale and proportion when modelling from scratch, so reference images help you stay on course and also enable you to capture detail.



16 SLICE IN RHINO

To start slicing up the parts in Rhino, you need to decide where you want to slice the parts. Use the Curve command tool to draw the line and make a closed curve, and Extrude Curve to make a solid one. By using Mesh Boolean Difference, you can separate the required part from the rest of the model.

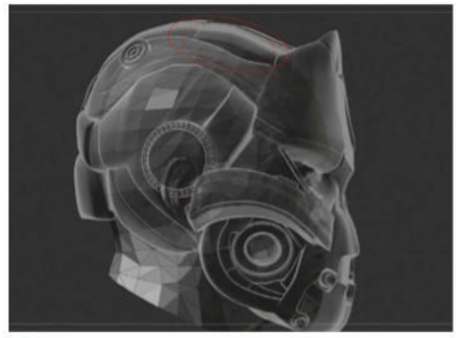


17 ADD JOINING PARTS

Search for a download the 'Klik' part on **myminifactory.com**. This joint enables you to connect the different parts together after printing them; you will need to orientate the joint parts onto the mask. To connect them to the rest of the model, use Mesh Boolean Union. Save each part individually.

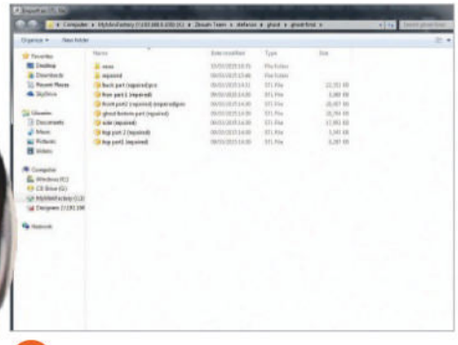
18 IMPORT TO ZBRUSH

From Rhino you will need to export all the separate parts you have sliced back into ZBrush as separate subtools. Once you have done that, you will then need to merge each individual subtool into one large subtool by clicking the Support tool palette and picking Merge Visible.



19 SIZE WITH A TEMPLATE

You will need to size the model to make it big enough for a human head. Do this by importing either a scan of your head or a ZBrush template of a head. You will then need to orientate the mask around the head; use the Move brush to make adjustments to the mask so that it fits comfortably.



20 EXPORT ALL THE FILES

In the Subtool palette you will need to split the parts using the Split Similar Parts command – this will enable you to separate the parts again. Now you need to Dynamesh each part individually to make sure that they are all solid, and then decimate all of the objects as you did previously.

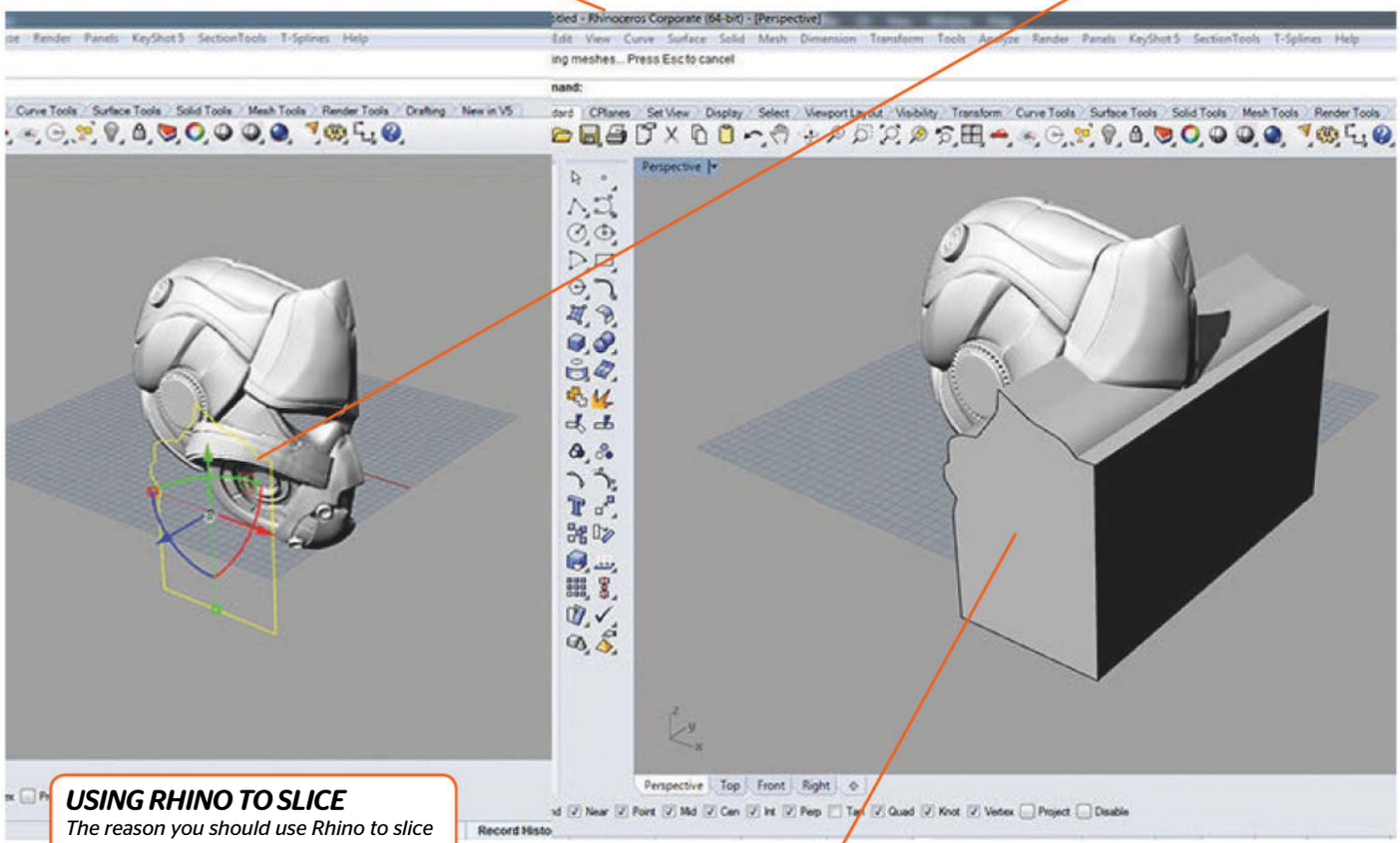
21 PREPARE IN NETFABB

Import all the files into Netfabb to make sure that all the parts are printable. Check there are no holes or open cells to ensure a clean print. Also import a scan or head template,so you can scale the mask to the dimension of your head to make it wearable. Once done, export the files onto a USB ready for printing

PREPARING AND SLICING THE MODEL

You will need to head into Rhino in order to figure out where to slice up the parts

Draw a closed shape using the Curve tool to begin your cut



USING RHINO TO SLICE

The reason you should use Rhino to slice is that it is quicker and more efficient than doing it in ZBrush. Ultimately this does come down to personal choice, however Rhino's Slicing tool offers a more accurate way of cutting up a model.

Extrude the closed shape through the model. Use the Mesh Boolean Difference tool, select the two parts and hit Enter. This will separate the part inside the extruded shape, thus causing it to separate from the model

22 OKAY FOR PRINTING

Once you have made sure that the file is okay to print, load the STL files into your slicing software of choice – this will vary depending on personal preferences but any is fine to use. Click the Slice button to initiate slicing and then wait until it's completed. With that done, you are ready to 3D print.

23 PAINT TO FINISH

For a professional finish, use a spray booth and a clear reference image for what you would like the paint job to look like. For this model we went for a mechanical helmet with a white ghost face over the top, keeping to dark shades of grey, white and black to achieve the metallic effect.

Model a Troll Slayer

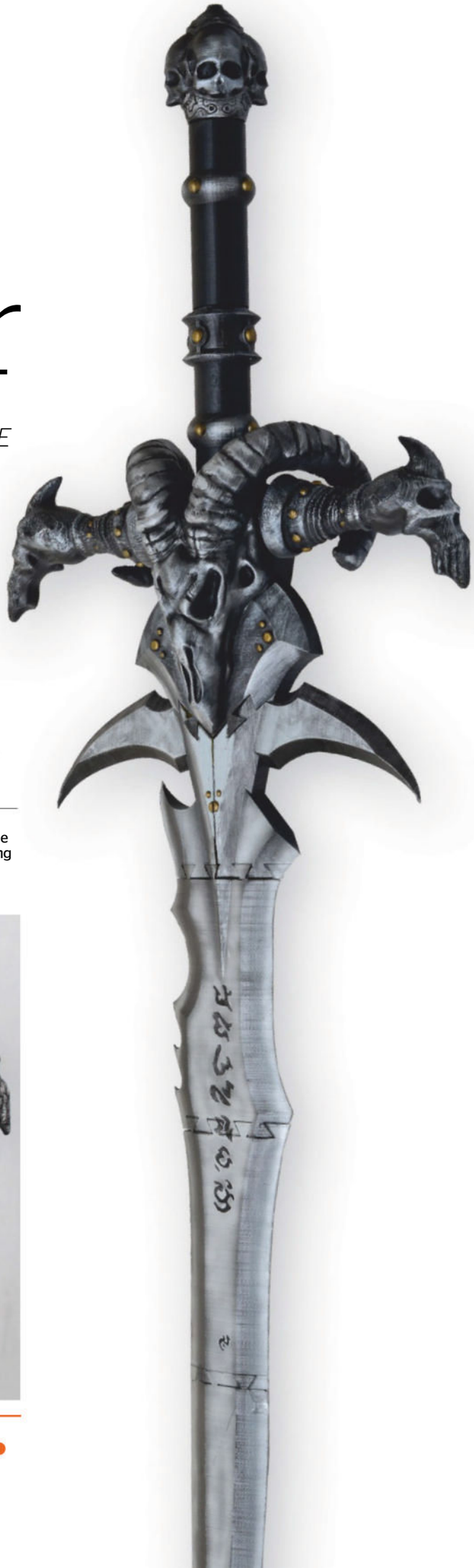
FORGE TWO ELEMENTS IN TWO PIECES OF SOFTWARE AND JOIN THEM INTO THE ULTIMATE SWORD

The purpose of this tutorial is to take two 3D modelling disciplines and then mix them together to make one model. By learning how to do this, you can ensure that you will achieve the very best results in your models, because you will be free to pick the software that specialises in the look that you want to get at that stage of your design.

In our example here, the model has fine organic detail that can only be achieved in ZBrush. However, it also needs accurate glue-free joins, which can only be achieved in SolidWorks. Once complete, these two elements can be put together to make one amazing object – the Troll Slayer. In this tutorial we will show you how to create the basic skeleton on a sword, and then create joins. Then we will create models that will fit around the skeleton in ZBrush. Finally, this will then all be meshed together to create one object in Meshmixer.

Maker: Kirby Downey is a product designer from South Africa, currently based in London. He specialises in taking objects and adding a technical and mechanical side to them, first making them work mechanically before adding a story to each product using shapes and forms

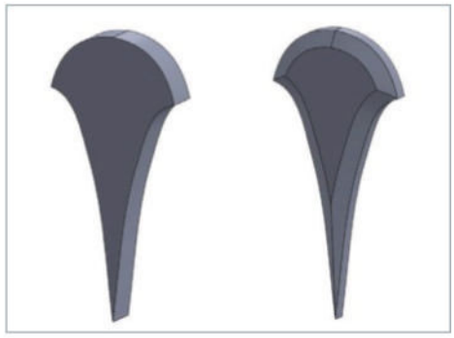
Profile: myminifactory.com/users/Kirby%20Downey



Printer used	***App name***	***Filament used***	***Complexity***
Ultimaker 2	*SolidWorks, ZBrush and Meshmixer*	*PLA, 640g*	●●●●●

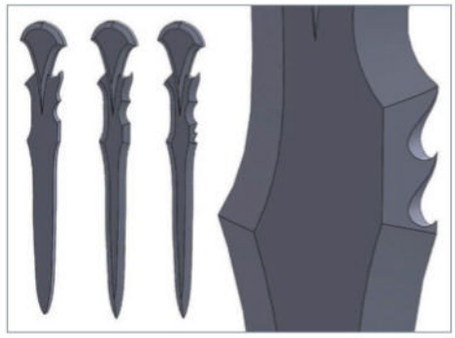
01 PLAN A STRATEGY

You need to work out what's going to be done in what software. For this model the skulls were created in ZBrush, and the sword and skeleton of the handle and hilt was done in SolidWorks. Meshmixer was used to put it together, allowing the tolerance and scale of the joins from SolidWorks to be kept.



02 MAKE A BASIC SKELETON

To start a build like this you need to create a skeleton of the sword in SolidWorks. This is a guide to where your sculpted pieces will be placed. Focus detail at this point on areas where there will not be any sculpted parts on it. First we started with the hilt, using that as a mid-point and a reference of scale.



03 CREATE THE BLADE

The blade is the largest part of this build and the easiest to do in SolidWorks. Leave some details for later, like the small serration on the top of the blade. The chamfer won't flow though these areas as easily if you do them first. Use Fillet>Chamfer to add this, ensuring you cut out afterwards.

04 MAKE THE HANDLE

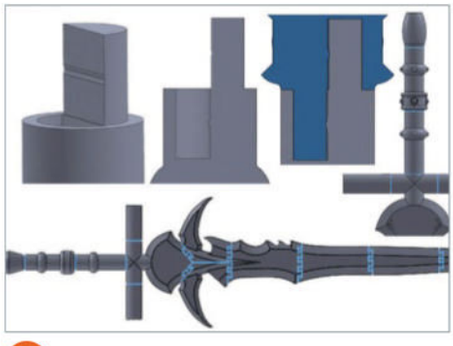
The next thing to do is work on the rest of the hilt, starting with the skeleton. For this you can just make simple rods – they need to be thick enough to enable the joins to be placed but also thin enough that they won't be larger than the sculpted areas, and then show through.

05 ADD DETAIL TO THE HILT

Add all the necessary details to the hilt, depending on the look you're going for. Only add detail that is easy to achieve in SolidWorks, which in this case is the markings on the hilt. Don't spend a lot of time creating details that can be created faster in another software.

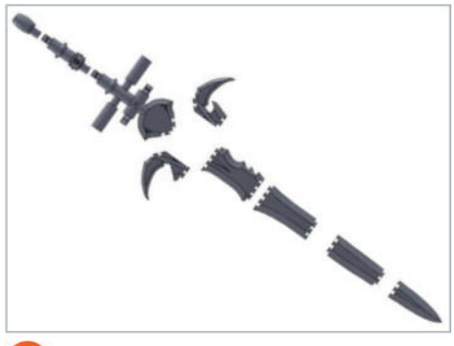
06 CUT THE BLADE UP

SolidWorks is the best to create cuts, tolerance and testing of fits, so create these before adding more detail in ZBrush. Cut up your sword, considering your printer, orientation and support material. Use the zig-zag joins similar to those in the sci-fi gun tutorial, which are available on MyMiniFactory.



07 CUT THE HANDLE

Since the handle is round, create a male and female joint that locks into place with a snap fit. Extrude a semicircle, then extrude another opposite it, adding a 0.3 mm tolerance. You can use glue or make a simple clip for added strength, or both for super-strength. Download the join from **myminifactory.com**.



08 EXPORT THE FILES

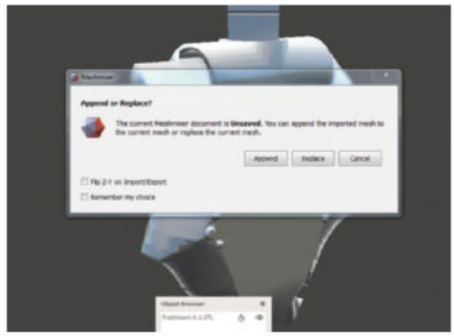
Export individual files from SolidWorks as STLs, so you can import them into ZBrush as guides. You can't sculpt on the SolidWorks files as the mesh is extremely low poly, and when you Zremesh a SolidWorks file you lose the accuracy of the tolerance, joints and scale. It could even destroy the topology.

09 SCULPT THE DETAIL

Now working in ZBrush, sculpt out the organic parts around the imported parts; use those as a guide to the limits of the space you have to work from. We modelled the ram's head, the skulls on the cross guard and the four skulls on the pommel. Only add detail to the surface areas that will be seen.

10 DELETE AND EXPORT

Delete the imported files once you have finished sculpting all the detail you want in the hilt. Make sure that the files you are using have a poly count of 200,000, as this will allow everything to run smoothly in Meshmixer. Export the files as STLs to import into Meshmixer.

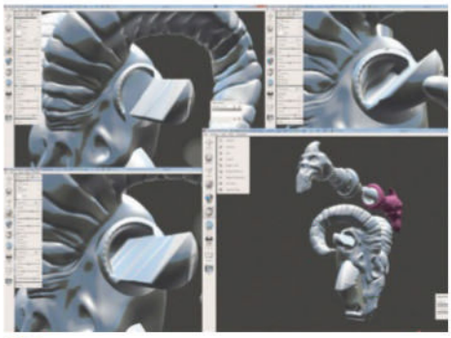


11 OPEN MESHMIXER

First import the body of the sword from SolidWorks (see 'Importing into Mesmixer', opposite). Now import the SolidWorks files you're adding the ZBrush files to. Add the next model to the existing environment with Import>Append. We imported the bottom of the hilt, the cross guard and sculpted parts.

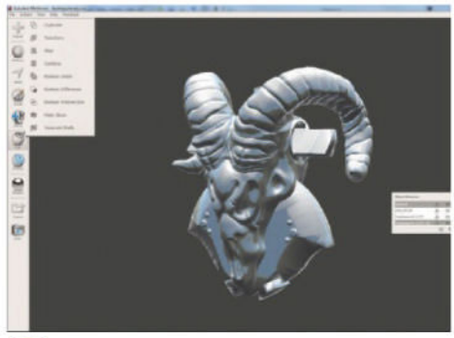
12 ALIGN THE MODELS

Move and scale the ram's head to align it with the bottom of the hilt. You can do this with the Transform tool under the Edit tab. If you see that some changes need to be made to the models, you can always go back to SolidWorks or ZBrush to make the various edits and then re-import.



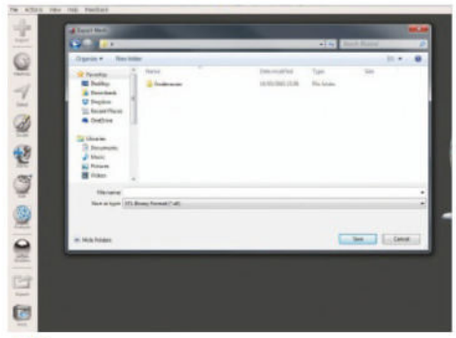
13 SCULPT AWAY WASTE

Once you are happy with your alignment, start getting rid of material that is in the way of the joints. Using the Push2 brush, hold Ctrl while sculpting to slowly push the material on the skull instead of pulling it out. Continue this until you can clearly see the inside surface of the joint.



14 COMBINE THE MODELS

Once all the material is sculpted and you are happy with the result, combine the hilt with the joint and the sculpted part. This is done by selecting the objects you wish to join in the object browser, then clicking Combine. This will fuse the selected parts together and have them ready for print.

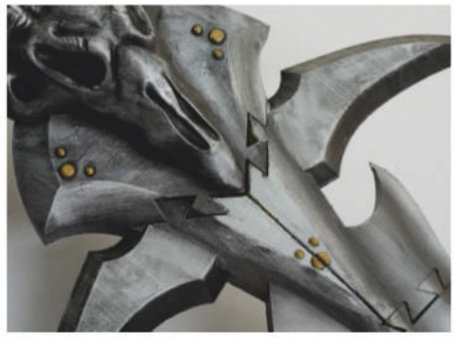


15 EXPORT TO PRINT

Now export all of the fused parts from Meshmixer as STL files so that they can be sent to your slicing software. This is done by simply clicking Export in the side toolbar. Once this is done you will be able to import your STLs into your particular slicing software without any problems.

16 SEND TO PRINT

Take advantage of each blade piece's small surface area on the bed; you can print them at the same time. With the ram's head, play with orientation to get it to fit perfectly on the bed. Before printing the combined files, check the preview to ensure they'll look right. Correct them in Netfabb if there are errors.



17 CLEAN AND ASSEMBLE

Clean the support material and assemble your model. The joins designed for this are snap-fits. They will pop right into place and hold their position. If they don't fit smoothly, knock it into place with a rubber mallet. Due the size of the thing, this model was first painted and then assembled.

18 PAINT AND FINISH

Start with black acrylic for a dark undercoat, then airbrush the blade with a silver acrylic in the centre and the edges for highlights. Use a grey polish for the hilt and gilding wax to highlight the areas that protrude more. Add bronze detailing, then add a clear coat to seal the whole paint job.

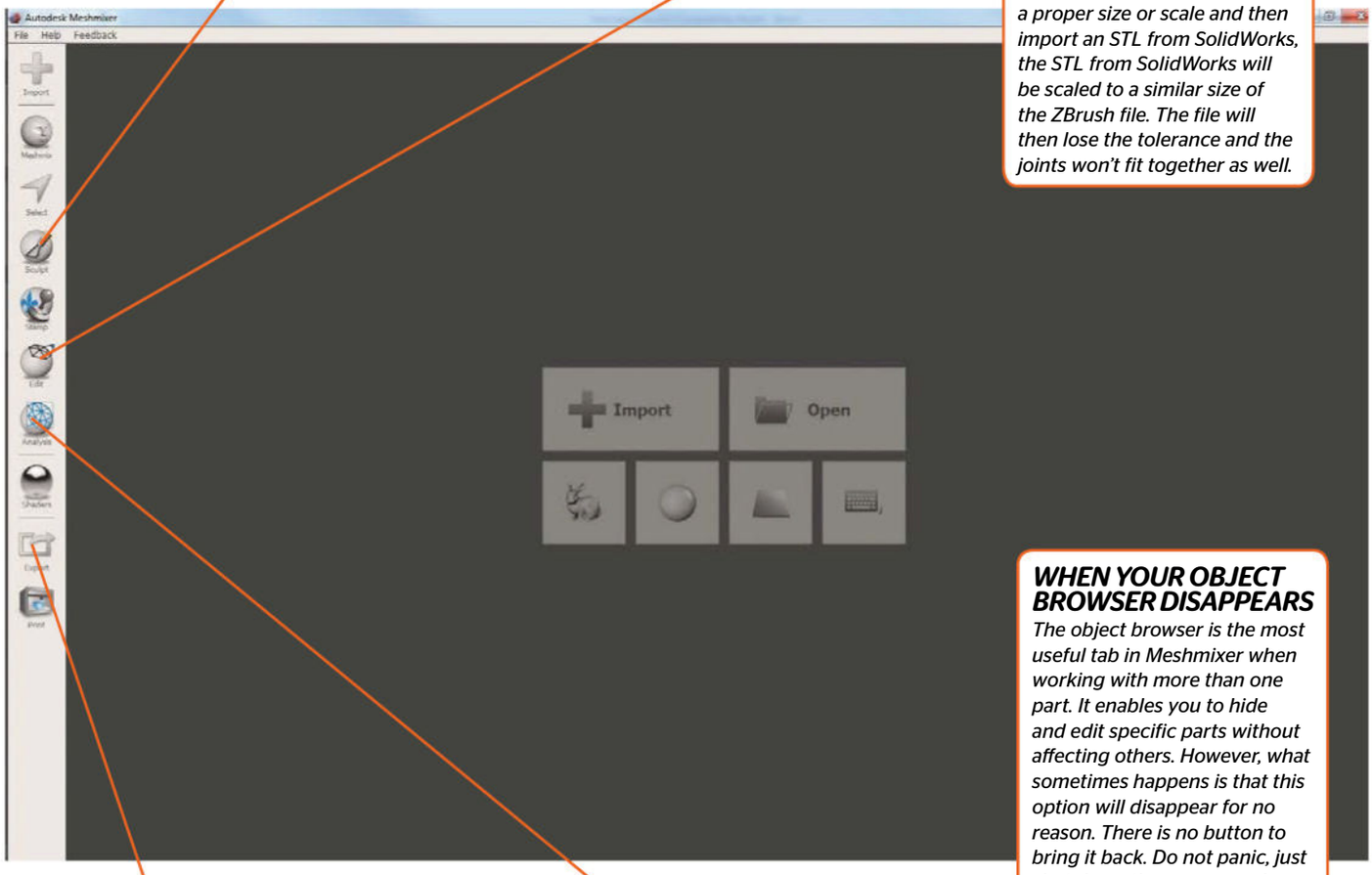
19 LOOK AWESOME

As this model is lightweight, plastic and can't do any bodily harm, this prop can be classed as con-safe. What this means is that this weapon will be allowed to be taken into conventions as a cosplay item. Since it's lightweight, it is easy to carry and won't be a strain on you.

MESHMIXER INTERFACE

This is the tab where you find all your sculpting tools. These are limited but useful for making simple, quick and easy adjustments

This tab holds tools like Transform, which moves and scales objects, as well as Plane Cut, which you can use to make your cuts. Everything you need to edit the basic mesh is found here



Here you can export your models. You have a variety of options, all of which are printer-friendly. Meshmixer also allows you to slice straight to your printer

This tab allows you to inspect your model for holes or areas that are too thin. The Overhangs tool enables you to add the Meshmixer support. This is great for organic objects

IMPORTING INTO MESHMIXER

This is important. When importing into meshmixer, the first object you import into the environment will be set in that object's scale. When you import an STL from SolidWorks, the model will retain its scale and dimension. If you start with a ZBrush STL that doesn't have a proper size or scale and then import an STL from SolidWorks, the STL from SolidWorks will be scaled to a similar size of the ZBrush file. The file will then lose the tolerance and the joints won't fit together as well.

WHEN YOUR OBJECT BROWSER DISAPPEARS

The object browser is the most useful tab in Meshmixer when working with more than one part. It enables you to hide and edit specific parts without affecting others. However, what sometimes happens is that this option will disappear for no reason. There is no button to bring it back. Do not panic, just shut down the program when it happens. To get the object browser back, simply press Ctrl/Cmd+Shift+O.

PART 1

From scan to print

LEARN HOW TO CREATE LIFELIKE 3D MODELS OF A PERSON BY SIMPLY PHOTOGRAPHING THEM USING A METHOD CALLED PHOTOGRAMMETRY

Due to its ease of production, non-destructive process and high-quality results, 3D scanning is a process that is already being applied to multiple industries. It's difficult to avoid the technology that has been so heavily featured in the media in recent times; it has been used in the production of prosthetics and bodily organs in the medical industry, CGI in the video game, film and entertainment industries, as well as used in the documentation and archiving of cultural artifacts.

3D scanning is the process of analysing an object or an environment through its form, dimensions and colour. By gathering this data it is possible to create accurate representations of an object.

There are various methods in which objects can be scanned, from hand-held real-time to infrared and contact – these all require some pretty high-end pieces of equipment. The most accessible and cheap method, however, is to scan the object through a process called photogrammetry. This method can be done simply using a smartphone or DSLR camera; the general rule of thumb is that you want to feed the computer with as much detail of what you are scanning as possible by photographing it from every angle.

Maker: Stefanos Anagnostopolous studied 3D animation and multimedia production. He often takes inspiration from movies and video games, and enjoys hard surface modelling

Profile: myminifactory.com/users/Stefanos

01 CHOOSE YOUR SUBJECT

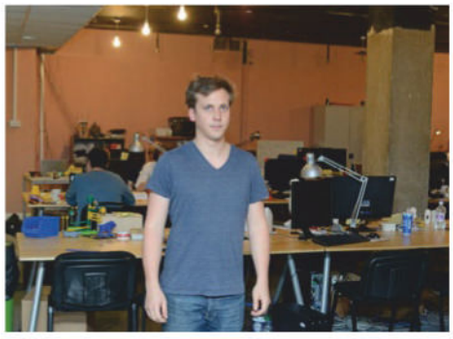
Find a subject to photograph. For an ideal scan, make sure that the subject's clothing is neither too dark nor too light as this can confuse the exposure of the camera. Anything that is too over- or underexposed is missing tonal data and therefore will not be picked up by the camera.

02 FIND A LOCATION

Ideally you want to photograph on an overcast day as this is when the colours are most muted. Be aware that when there is strong sun above the subject, it will cause extreme areas of contrast and shadows that can distort the scan. You can photograph indoors, if you prefer.

03 SET UP THE LOCATION

Another important element to get right is to ensure that the background has contrast against your subject. This is because the camera will pick up points of reference behind the subject in order to join the photographs together. Take a few test shots if you're not sure and see how they look.

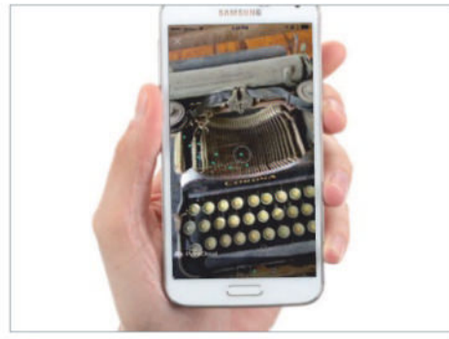


04 SET UP THE PHOTOS

You will want to make sure that the subject is well exposed in every photograph in order to avoid losing any data, which can confuse the scanning software. If you are familiar with a DSLR then shoot in manual and avoid flash, adjusting the exposure accordingly if there is uneven lighting in the environment.

05 USE A DSLR

Follow the basic rules of photography: ensure each image is in focus and properly exposed – anything that is under- or overexposed will result in a loss of data and won't be picked up by the processing software. Shoot low to medium quality JPGs; shooting in RAW only slows down your processing speed later on.



06 USE A SMARTPHONE

It's possible to scan with your iPhone using either the 123D Catch or Trnio apps. These will use your camera's automatic settings and come with great interfaces telling you exactly where you need to photograph, notifying you if the photographs are incorrectly exposed or too blurry.

07 SCAN IN REAL-TIME

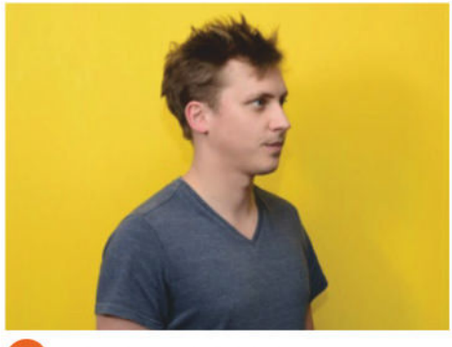
This is advised if you are willing to invest in equipment like an Artec 3D scanner. This is a method that takes large batches of photographs in a short space of time. The results are often much more accurate, and the process is much faster, but you need to be attached to a computer at all times.

08 USE A SCANNING BOOTH

A scanning booth is a rig of, on average, 50-60 cameras that are released at the same time to generate an instant scan of an object or person. iMakr's professional Mini-You services (the rig is pictured in the first two steps) are a great way of obtaining a quick mini-model of yourself or a friend.

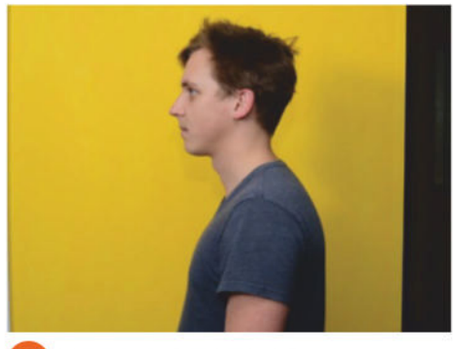
09 START TO PHOTOGRAPH

Take a photograph of your subject with every step that you take around them. Make sure that you do a full rotation at eye level, like a panorama, keeping the subject in the centre of each shot. During this first rotation try, to make sure that your subject does not move too much.



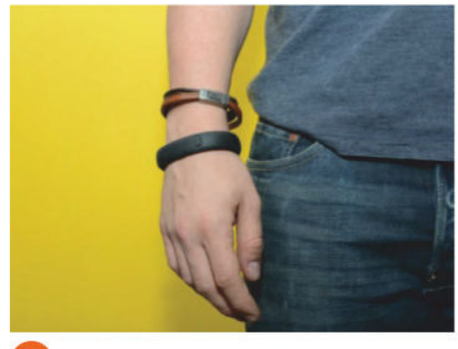
10 ROTATE AGAIN

Once you have completed your first rotation and taken about 30-40 photos, go around again at different heights to make sure that you have every detail of the portrait included in the scan. Use a chair or a ladder to get above your subject, and crouch low so you can capture details under the chin and ears.



11 KEEP ROTATING

It's always wise to take as many photographs as possible in order to feed the computer with all of the information about the subject. Try to get some good aerial shots of the head because hair can be quite tricky to clean up later, and the more photos you get of the head and hair, the better!



12 FOCUS ON DETAILS

If there are any defining features in the person or object that you scan, make sure that you photograph them, such as a hand or piece of jewellery. Also photograph the subject from the front, behind and the sides so that if you need to clean the subject later on, you have reference images to work with.

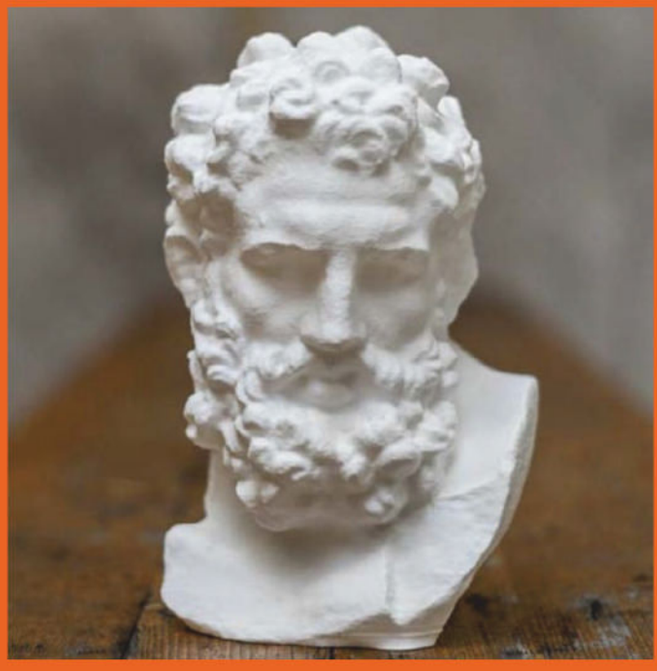
SCAN THE WORLD

From scanning body parts to create models for scientific study and prosthetics to using the models in the production of clothing accessories and fashion, the possibilities in scanning are limitless. All of these applications can be achieved once you understand photogrammetry and 3D scanning.

3D scanning has a huge place in art as well. In May 2014, MyMiniFactory launched Scan The World, a worldwide collaboration to build an archive of sculptures in 3D. Each photographic representation is free to access, download and print. The project encourages those who have never touched a camera to scan artifacts in their local area to help build the worldwide archive of art.

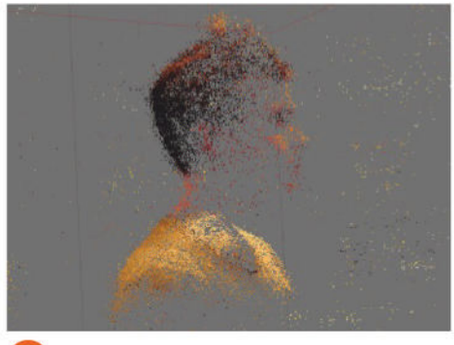
The possibilities this archive creates are incredibly valuable, breaking down the walls of the art institution and opening up art to anyone around the world geographically, and providing an important resource for the visually impaired. The sculptures themselves also exist to accurately preserve the scanned artworks so that they can be referred to in the future.

Scanning sculptures is incredibly easy (mainly due to the fact that they don't move!) so when you have tried this tutorial, give a few sculptures a go. Once you have, please email the photographs or processed scans to stw@myminifactory.com.



13 CHOOSE SOFTWARE

There are many processing applications. To learn the processing procedure, try Agisoft PhotoScan, which lets you tweak characteristics of the process. Autodesk has a couple of apps that are more automatic. If shooting on a smartphone, use 123D Catch. For more accurate results, try ReCap 360.

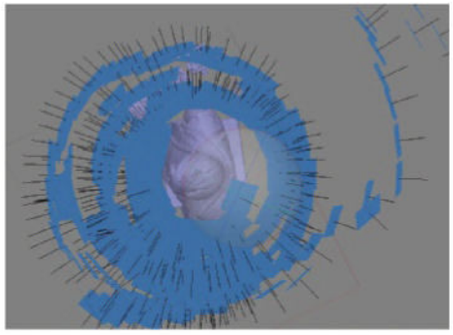


14 UNDERSTAND STITCHING

Each software follows a similar algorithm by simply stitching images together through a large number of points of interest, which are calculated from your imported photo data. This creates something called a point cloud, and these points are then compacted and merged in order to produce a mesh.

15 USE 123D CATCH

This software is relatively easy to use as the whole process is automatic – simply create a new project, import your images and click Go. This is a great piece of software for beginners looking to get started with 3D scanning and enhance their understanding of photogrammetry in general.



16 USE PHOTOSCAN

Agisoft's PhotoScan software enables you to process your scans step-by-step. This gives you the opportunity to curate each stage of the model creation, manually aligning photographs and also dictating which parts of the scan will be turned into a mesh. It takes longer but leads to greater accuracy.

17 USE PROJECT MEMENTO

Project Memento is another piece of cloud-based processing software from Autodesk. Memento uses a brand new algorithm called ReCap 360, which provides high quality results and also enables your scans to be fixed and prepared for print in the software itself. Video input is also compatible.

18 TAKE THE NEXT STEP

Once the software has created a mesh you will be left with a textured model. This can be exported as an OBJ or GCODE in order to be cleaned up or printed straight away. Import this model into your sculpting software of choice, where you will be free to clean up the surfaces and make any necessary additions.

PERFECTING YOUR SHOTS

Note how the details in the background move around the subject during the rotation. This is important in creating a successful, smooth scan

Each photo is taken at an equal distance from the last one and the subject at the centre of the ring, ensuring that every detail is included

The first rotation needs to include the whole subject in one shot. It is only once you have done this that you can start to photograph certain reference images

TRIANGULATION

Triangulation is an aspect of photogrammetry where it will take two points of reference from the camera: one from the background and another compared from the object in the foreground. You can see in these sample scan shots how reference points in the background, like the exit sign, move around the subject – this is an important part of making a successful scan.

It is very important that your subject remains perfectly still during the entire scanning process. Make sure that they are comfortable before you start scanning

Make sure the background contrasts well with your subject. For instance, if your subject is wearing a white shirt do not photograph them in front of a white wall

If your subject has long hair, make sure it is tied up. Try and avoid things like big colourful glasses and accessories as this can confuse the processing software

Printer used	App used	Filament used	Complexity
Makerbot Replicator 2	ZBrush	PLA	●●●○○

PART 2

From scan to print

NOW USE ZBRUSH TO CLEAN UP YOUR 3D SCANS SO THEY ARE READY FOR PRINTING

For this tutorial you will be learning how to take your scan and clean it up so that it is ready for 3D printing. Nine times out of ten you get a scan that is messy, so knowing how to clean things up is a great skill to have because you will want to ensure that you get as much accuracy and as little noise as possible in your model. Here we are going to focus on sculpting a 3D-scanned bust in ZBrush by importing the messy broken scan and re-working the model. We'll also look at how to capture final details using some of the reference images that you took later in the scanning process – you should make use of these references as frequently as possible. Particular attention will be paid to sculpting in the missing detail and working on the correct proportions. Finally, we will show you how to prepare the finished files for 3D printing.

We've opted for a miniature bust but you can aim for whatever size you like, depending on the size of your printer. Just be sure to consider the dimensions of your model, the resolution and tolerance of your printer, and then work on the detail in your model accordingly – with our print, for example, it wasn't exactly crucial to model individual strands of hair on the fringe! The larger your final print will be, the more detail you'll need.

Maker: Stefanos Anagnostopolous studied 3D animation and multimedia production
Profile: myminifactory.com/users/Stefanos

01 IMPORT INTO ZBRUSH

Open up ZBrush and then import your 3D-scanned model into the software to get started. Once the model is inside ZBrush the first thing you will have to do is duplicate it – this is a safety measure in case you make a mistake; always duplicate your original model before anything else.

02 REMOVE GEOMETRY

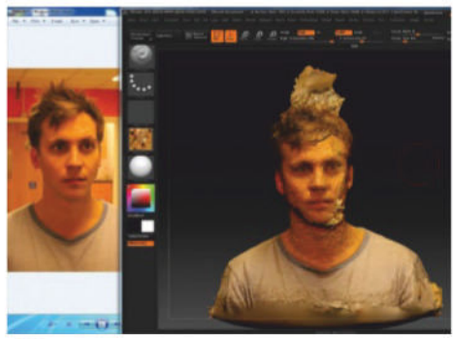
Now remove any geometry that's not part of the model, which your scan will have picked up from the background. Cut the geometry out by using the Lasso tool; this is a great tool for drawing around geometry accurately. Remember to use your Intensity and Draw Size sliders to adjust the tools performance.

03 CLOSE HOLES

One side effect of removing the unwanted geometry is that you could create holes in the model where this noise made contact with your main model. You will need to repair these and any other inconsistencies. Use the Close Holes button in the Geometry toolbar on the right-hand side of the screen.

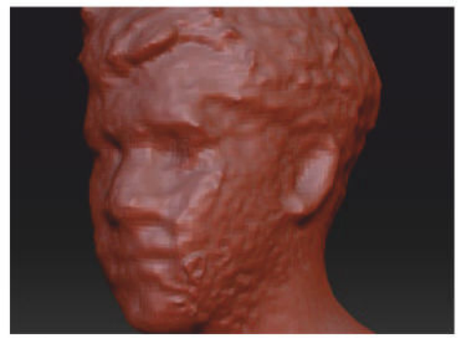
04 DYNAMESH THE MODEL

Once you have closed the holes on the sculpt, you will need to dynamesh the model to re-topologise geometry – this is a great way to join all the polygons together. It is important to make sure the model is watertight, meaning that all the surfaces are joined and are considered one solid object.



05 PROJECT NEW MODEL

You will then have to project the original model to a new low-poly model in order to have the details and the polypaint data copied across. On the new model, work from the lowest sub-division level (i.e. lowest number of polygons) to the highest, and one level at a time.

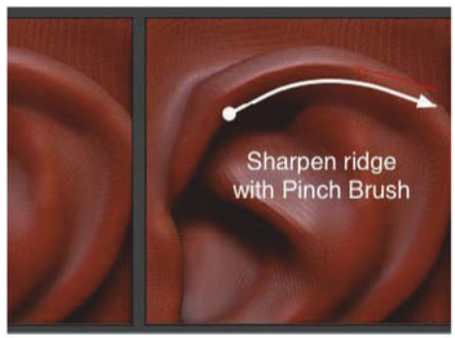


06 SMOOTH THE BUMPS

Bumps across the model's surface can be evened out using the Flatten brush, followed by the Smooth brush for final clean-up. Don't use just the Smooth brush or you will lose all your scanned clothes folds, skin texture, facial features, etc. Use reference images to accurately capture the scanned details.

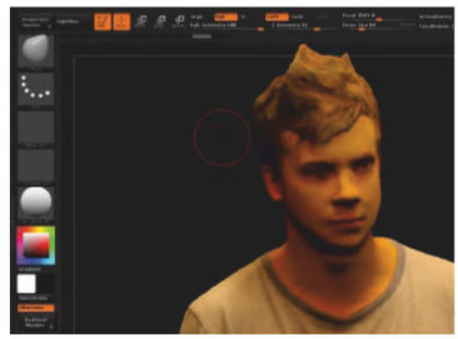
07 USE MULTIPLE BRUSHES

At each level, use a combination of brushes – Smooth, Clay Build Up, Move, Slash3, Pinch, Flatten, Trim Dynamic, etc – depending on the level of detail you want. These enable you to re-create details from the reference images. The sculpting is trial and error; go over the details a few times with each brush.



08 USE THE PINCH TOOL

Pinch pulls vertices together; it is, roughly, the inverse of the Magnify brush. It is very useful for sinking in detail for creating clothing and wrinkles, and adding hard edges to any form. Use Pinch along the edges to make surfaces sharper; remember you're cleaning a soft model, so need rounded surfaces on the face.



09 TWEAK WITH MOVE

Move can be used to modify facial features, indicate emotions or achieve a natural, more asymmetric face, Once you have used the other brushes to remove the bumps, Move enables you to create more realistic facial features. Remember to use different intensities and draw sizes for different effects.

CLEANING UP YOUR SCANS

Depending on the method that you chose to create your 3D scan, and the quality of the equipment that you used, there will be some degree of noise in your scan that needs to be removed before you can get that crisp, print-ready model. There are just a couple of key things to bear in mind as you clean up your scan.

MESSY START

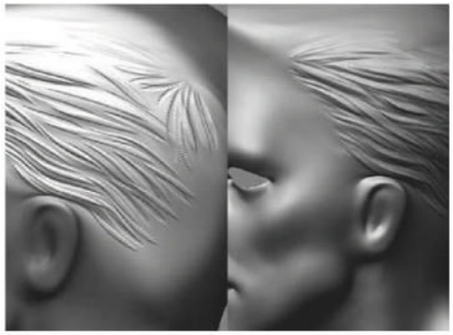
A 3D-scanned file will always lose a little bit of detail and has the chance to come out very messy – but don't panic! This is fixable, and also why these techniques are so important for you to learn.

BRUSH IN DETAIL

The brushes used in this tutorial enable you to sculpt facial features and details. Play around with draw sizes and brush intensities for different details, and use Zsubb and Zadd to change brush styles.

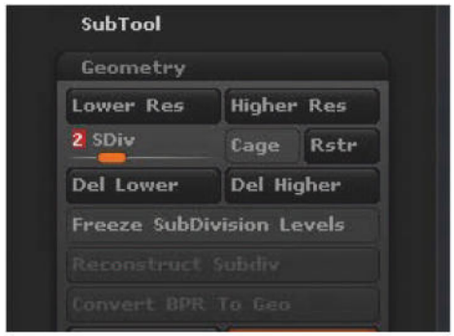
TRIAL AND ERROR

The workflow for repairing 3D scans is a lot of back and forth, always re-working detail into the sculpt then moving up into a higher subdivision and starting the process again. Repeat until satisfied.



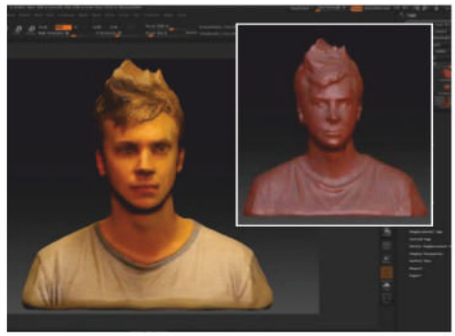
10 SCULPT THE HAIR

Use the Clay Buildup (with no alpha) and Move brushes for most of the blocking, then work on the details using the Standard brush. You can also use Dam Standard to sharpen certain parts, and the Smooth brush to remove nasty brush strokes. These brushes should give you the general hair shapes.



11 USE SUBDIVISIONS

Keep working through your subdivision levels, adding more and more detail every time you increase the level and also using the brushes we've mentioned so far. For heavier lines, press harder or increase the intensity of the brush stroke. Again, use your reference images for this.

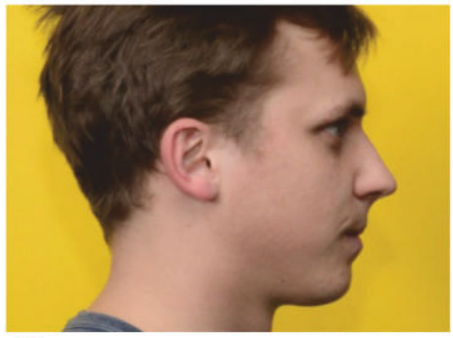


12 REMESH AND PROJECT

As you did back in step one, duplicate your model. When you Dynamesh in ZBrush you will lose a lot of the detail that you have worked on. To prevent that, you can project the duplicate sculpt back onto a newly Dynameshed sculpt and your details should then be saved.

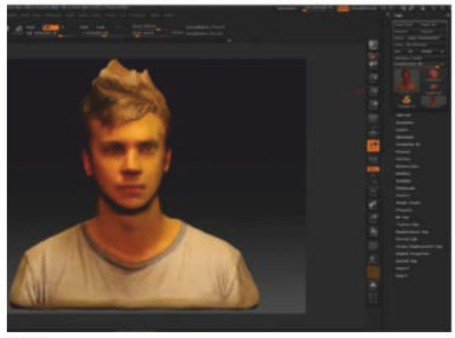
13 BEGIN TO POLYPAINT

Start polypainting. Make sure you use the Standard brush and only RGB. You can put all of the painting details directly onto the model's polygons and then transfer that detail to a texture map when the painting is complete. Remember to stay at the highest subdivision level



14 PAINT GENERAL SHAPES

Start by painting the larger parts of the model, including the skin tone, hair colour and clothes, and also focus on using natural colours in order to keep your model as realistic as possible. Look at the reference images again to see the tone and contrast of the colours used.



15 ADD COLOUR

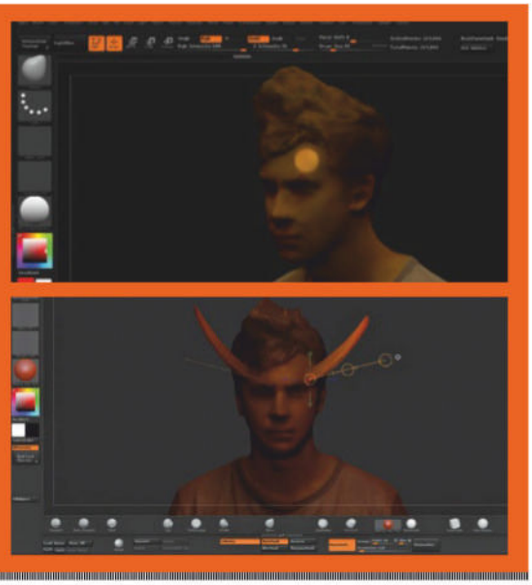
When you are happy with the result, add colour on top of your model, again using your reference images. Polypaint enables you to add colour to each vertex in the model; go into the Tool palette and, under Polypaint, select the Colorize button. Play with different intensities with the RGB button on.

GETTING CREATIVE

Once you are happy with the accuracy of your sculpt from the 3D scan, you can start getting creative with it and look to adapt your scan into a unique piece of art. You don't have to go crazy here – you will only need three or four tools to transform your 3D scan.

As an example, this quick step will show you how to add horns to your sculpt and turn your scan into something more fantasy related. To create horns: mask your model using the Mask tool on the area where you want to add your bust's horns, such as the sides of the head. Next, invert the mask so that the whole sculpt is masked, except the area you want your horns. Select the Transpose tool from the Brush palette. Draw a line using the Transpose tool on the unmasked area and select the middle circle on the transpose line; this will pull out the unmasked section. Pull the shape out in the form of a horn.

Finally, use the Move tool and a high draw radius to shape the horns into sharper points. Take off the masking feature by clicking off the sculpt and use Smooth to finish off the horns.

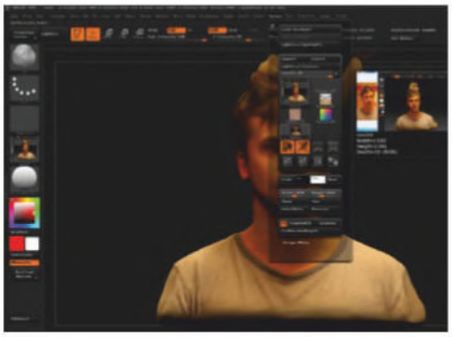


16 UV MAP YOUR MODEL

Once you have finished polypainting, you need to set up your model for texturing. The process is called UV mapping, and consists of making a 2D space based on the 3D geometry. This can then be used as a plane to add your texture. In order to do this, use the UV Master feature.

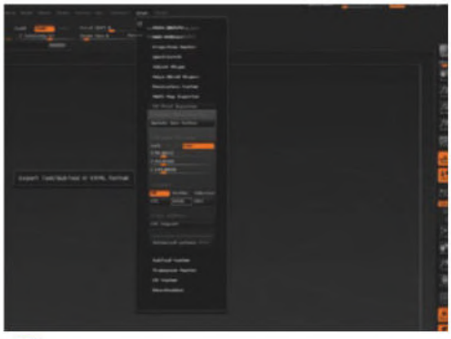
17 BUILD UP TEXTURE

Working on a clone, make a few polygroups corresponding to the areas that you want to texture better and click on the Unwrap button. Now copy and paste the texture to the previous polypainted model. The textures will be transferred over to the model that you wanted textured and painted.



18 CREATE THE TEXTURE

In order to do this, use the Texture palette; create a new texture, having selected the model that we just pasted onto the UV space beforehand. After that, select the Create a New Texture button from Polypaint and we can then have a good-looking texture for our realistic model.



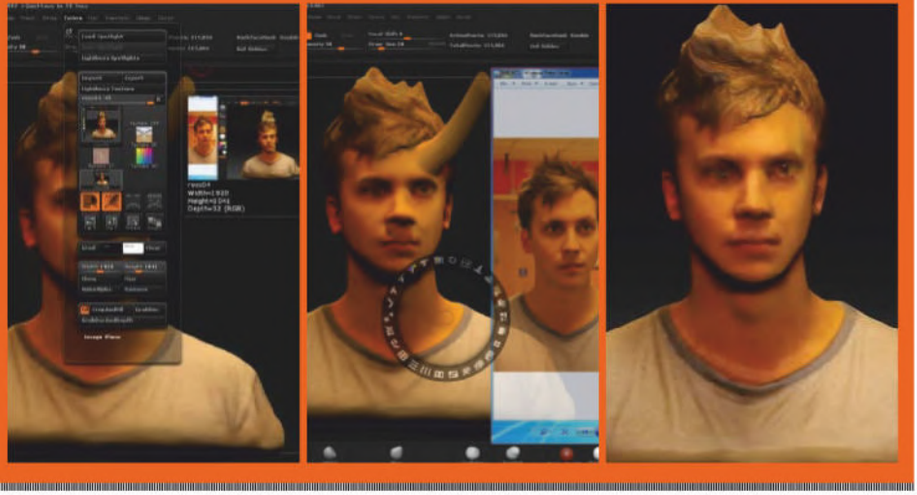
19 EXPORT AS VRML

The final step is using the 3D print exporter plugin. Select the VRML file extension to print in colour, select the PNG button for your texture and then click OK. This should enable you to print the model using the texture and polypaint that you have created in the previous steps.

Don't be afraid to go back to part one and re-shoot if your model is giving you too much trouble!

CREATING BETTER TEXTURE USING SPOTLIGHT

To get the most accurate detail and texture, use the Spotlight tool. This is great for texturing accurate, good-looking models that will look as realistic as possible. You will first need to get a reference picture of the exact thing that you want to model and texture. Open up your texture and import the reference image you want to capture. Click the Add To Spotlight button to import the reference image into ZBrush for texturing. Next, move your texturing image over the sculpt and press Z on your keyboard to activate the Spotlight tool. Now you are able to paint onto the sculpt and project textures and colours directly.



WHAT YOUR 3D PRINT SHOULD LOOK LIKE AFTER TUTORIAL

FOLLOWING THE STEPS TO GET AN AWESOME LOOKING 3D PRINTED BUST

If you have followed this tutorial correctly then your 3D scan will print with no support and should not require any post-processing. However, if you want to paint and finish the model differently, refer to the Finishing Techniques tutorial by the post-processing team from MyMiniFactory.

Once your print has come out of the printer the finished version should represent both the reference image and 3D model you have created

Using Spotlight texturing with the reference image should give you an accurate representation, with realistic colours, textures and shading

Smooth, Dam Standard, Pinch and Inflate are just a few of the tools you need to re-create facial features. Experiment with the others to find better methods

SELECTING A BRUSH STYLE

Remember that there is a plethora of brushes to choose from. Each brush will create a specific effect, so you will need to experiment a lot with the palette, different strokes, draw radiuses and intensities to get the most out of the brushes. Remember that there are also the Zadd and Zsub features, which will change the behaviour of the brushes; practice with them to better understand the characteristics of each brush.

TYPES OF FINISHING EFFECTS

Here is a copper powder and PVC effect bust, adding a realistic metallic sheen to our figurine.

Here is a verdigris effect on the same bust. This is used to create the appearance of weathered copper and add authenticity.

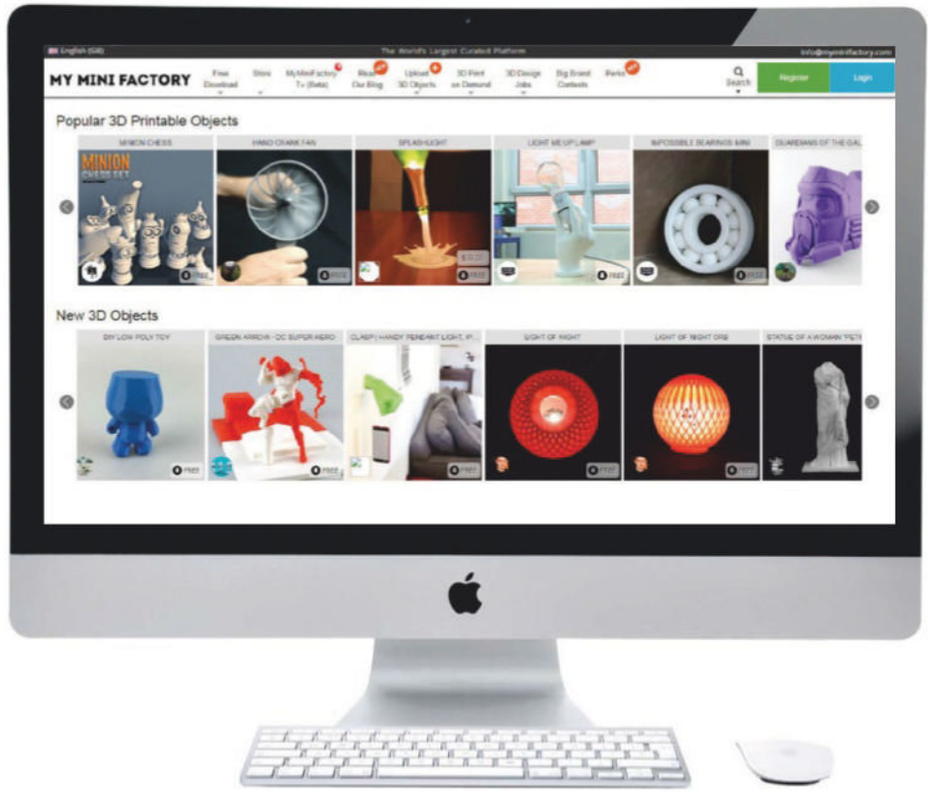
This is a stone effect, perfect for all kinds of statuettes. Learn more about this and the other effects in the Finishing tutorial.

Get started with MyMiniFactory

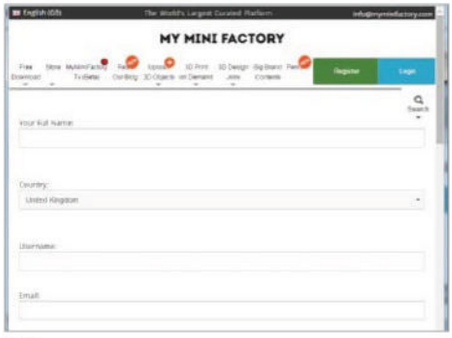
For more information, feel free to get in touch: info@myminifactory.com

So now you've had a chance to learn design for 3D printing from some of the experts over at MyMiniFactory, why not show off your work and get involved! If you're toying with the idea of having your work 3D-printed, this is a great way to get started. MyMiniFactory test-prints every object uploaded to the site – this is to ensure printability, meaning that users don't waste time and filament when printing designs from the platform. MyMiniFactory constantly welcomes new designers and would love to see you get involved!

MyMiniFactory adheres to open source content creation and distribution models. All 3D files are available for anyone to freely download, edit and then re-upload. Through this method, users are encouraged to create original as well as derivative content, provide feedback and support to other users, and generally stimulate the proliferation of 3D design and 3D printing technology by sharing and collaborating in a free and open manner.

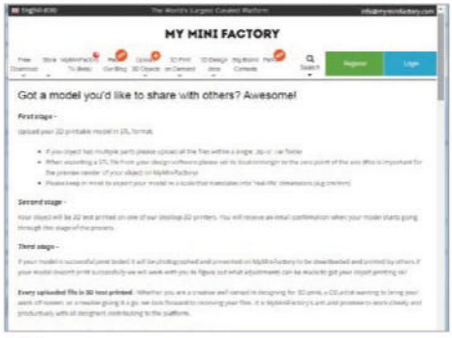


READY TO GET INVOLVED? JUST FOLLOW THESE EASY STEPS:



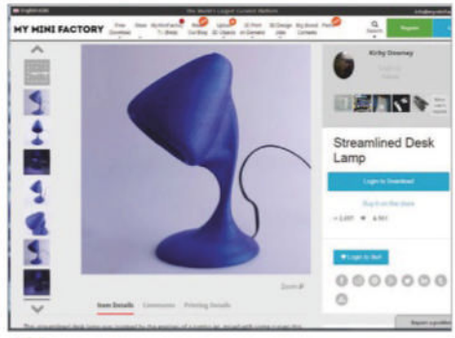
1 CREATE AN ACCOUNT

Click Register in the top-right hand corner, fill in all the relevant fields and hit Submit. Congratulations, you're now a registered user on MyMiniFactory! Once registered you can upload your designs, make money by selling prints of your designs in the store, broadcast on MyMiniFactory TV and even get tipped real money by your fans.



2 UPLOAD YOUR DESIGN

You will need to save your 3D designs as STLs before you upload them. Once you've done this, head over to **www.myminifactory.com/upload/object-upload**, or alternatively click the 'Upload 3D objects' button right at the top of the home page. Drag your STL into the space provided, add a brief description and hit Submit.



3 WAIT FOR YOUR 3D PRINT!

Your design will now be entered into the MyMiniFactory print queue, ready to be test-printed by the team. After the test print, the design will be uploaded to the public website for others to 3D print at home. After that, MyMiniFactory will send you your print – just add your address in the description box and state that you would like it sent to you.

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The 3D Art & Design ANNUAL

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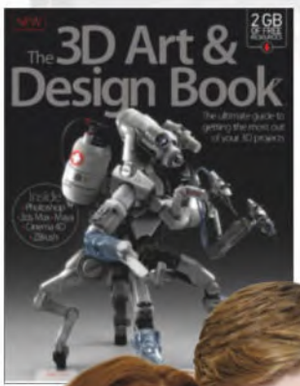

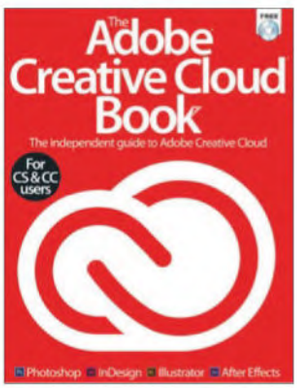

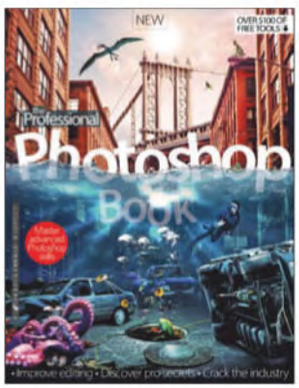

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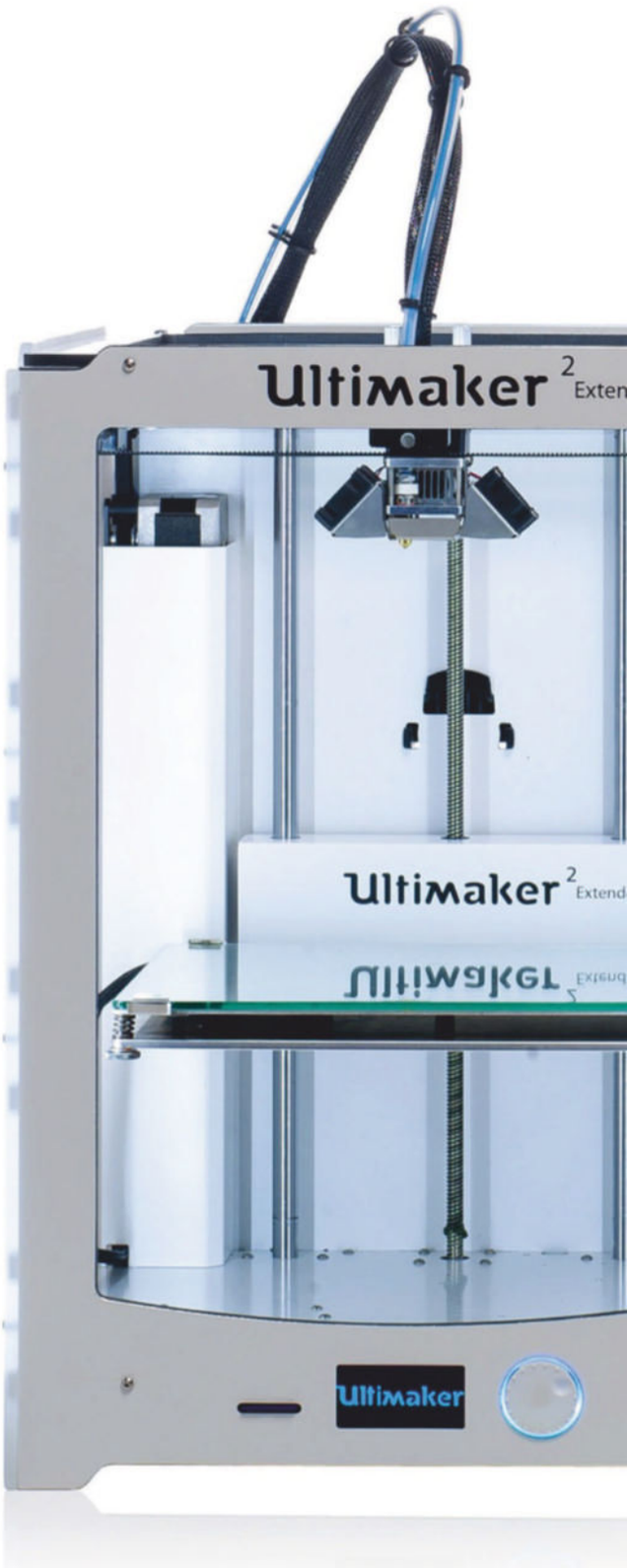
SIERT WIJNIA: THE ULTIMATE MAKER

CEO OF ULTIMAKER, SIERT WIJNIA, REVEALS THE INSIDE STORY ON HOW THREE PEOPLE BUILT AN OPEN SOURCE EMPIRE WITH A 3D PRINTER THAT CHANGED THE WORLD

Siert Wijnia may be the CEO of a globally-renowned 3D printer manufacturing company today, but just eight years ago, his life couldn't have been more different. A skilled mechanical engineer, he'd been working in a more managerial role at a firm that built large refineries for oil giants like Shell and BP.

"I was thinking, what am I doing here?" Wijnia begins. "It didn't feel totally right for me – it's just ending natural resources and not going to the next stage by thinking of new ways to do stuff instead. One day I thought, I can't change this business but I have a choice in what I do."

Luckily for Wijnia, it was just then that a brand new type of workplace had begun to spring up in towns and cities. Fab Labs – Fabrication Laboratories fully kitted to give people back the power of making – began to become popular around the world. It was the start of an open source manufacturing revolution, and one that would lead Wijnia somewhere that he could have never imagined back when he was managing the construction of refineries.



Launched at CES 2015, the Ultimaker 2 Go and Ultimaker 2 Extended (pictured) add two new size options to the Ultimaker product family

THE FAB LAB

"I started working at this little organisation, this Fab Lab, with a few people in the Netherlands that thought 'this is so brilliant – we should make it known to people'," remembers Wijnia. " Instead of managing everything, I could work with my hands again. I really loved that."

It was in those exciting early days at the Fab Lab that Wijnia saw his first commercial 3D printer. "I had heard about 3D printing when I was studying in the Nineties, however back then the machines were so enormously expensive that it wasn't even an option to start thinking about it. Then when I got into this Fab Lab we had a 3D printer just out there," he tells. "But it was about 40,000 Euros and the bucket of plaster that went into the machine was about one thousand Euros. I was a little bit disappointed – why was this so expensive? I had all the stuff around me to start building my own things with this 3D printer, but I was anxious to even use it because it was so expensive!"

GREAT MINDS

Wijnia was clearly not the only one asking that same question. In 2007, British engineer and mathematician Adrian Bowyer presented a radical new solution – one that many reported would bring down capitalism itself. He had invented the RepRap, a fully open source 3D printer than anyone could build themselves as the designs

ULTIMAKER SPECIFICATIONS

Layer resolution: up to 20 µm
Build volume: 21 cm × 21 cm × 20.5 cm
Print speed: 30–300 mm/s
Travel speed: 30–350 mm/s
Recommended filament diameter: 2.85 mm
Nozzle diameter: 0.4 mm
Print technology:
Fused filament fabrication (FFF)
Standalone SD card printing (UltiController)
Frame dimension X Y Z:
35.7 cm × 34.2 cm × 38.8 cm
Operation nozzle temperature:
180-260 °C
Software: Cura – Official Ultimaker
Usage cost: ~ €0.05/cm3
(material and power)
Supported Filaments:
PLA for Original,
PLA, ABS, and U-PET
for Original+

were free. The RepRap was also self-replicating, so one printer could be used to print 50% of the parts needed for another. Best of all, the technology was significantly cheaper than what had come before.

"I was totally grabbed by the concept – a printer that you could build yourself for 500 Euros," Wijnia smiles. "I was grabbed by the philosophy behind it. This 3D printer was an enormous tool, a liberation – having such freedom over what you can make."

He immediately decided to try to build a RepRap himself, and to get the whole Fab Lab group involved in the project. "It's quite a complex project so we started with a group of ten building these machines," he continues. The excitement of finally getting a cheap consumer 3D printer, however, was diminished by just how long the RepRaps took to build or replicate in practice. It took more than one evening a week over a full year to create those first ten machines, and even then only two were actually fully functional.

"It was a great journey – it was not good enough, but we learned quite a lot," explains Wijnia. "We decided to do another lot. It was quicker but it was still a lot of energy, and the results were better but not great." Though disappointing, the workshops introduced Wijnia to two other 3D printing enthusiasts that would change his life: Erik de Bruijn and Martijn Elserman.

Together, they slowly improved the RepRap's mechanical parts, making a brand new printer that would work faster and better. Using a laser cutter, a design was developed that wouldn't take a year to build or print, but a weekend. Before long, Wijnia, de Bruijn and Elserman were shipping all the parts needed to make their printer in one box. The design then even began to be made out of plywood – an instant hit.

"In those days we were thinking maybe we can sell a few in our evening hours, just for fun, and maybe we earn a little bit of money, just as a joke," Wijnia reveals. They had just started Ultimaker.

"HACKABLE WITHOUT LIMITS, THE OPEN SOURCE 3D PRINTER DIY KIT WAS EASIER TO ASSEMBLE THAN EVER BEFORE"

THE GROWTH OF ULTIMAKER

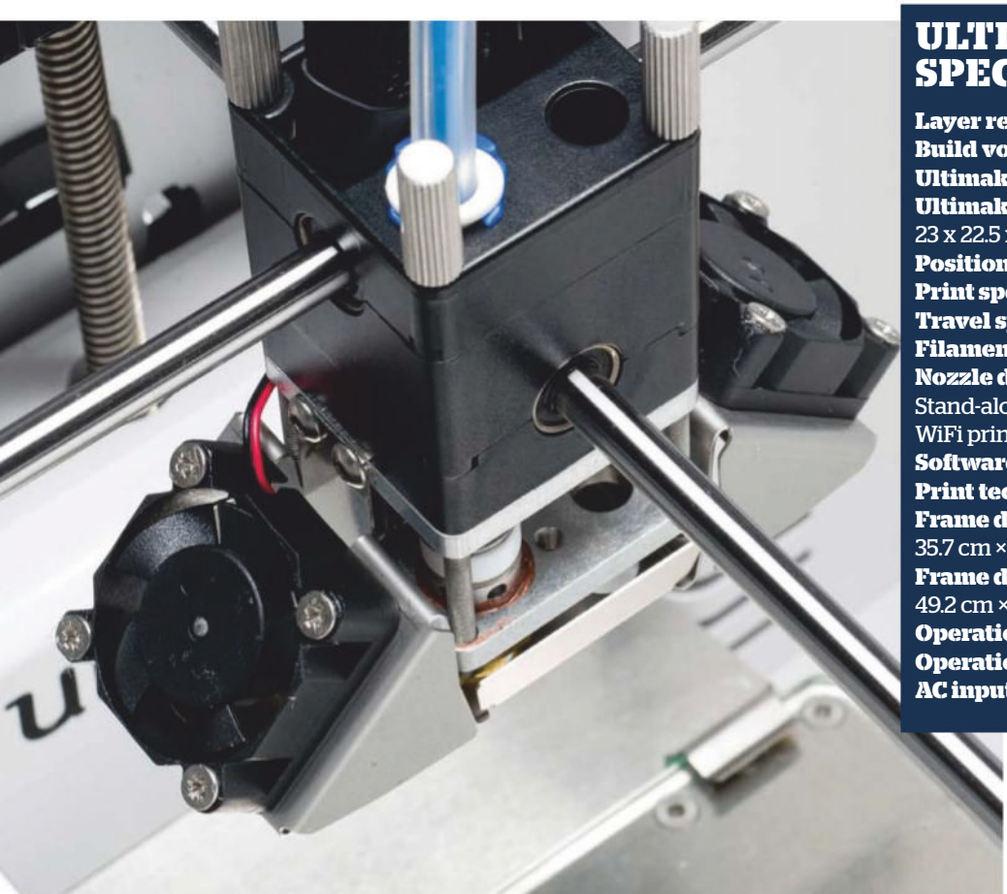
Now an internationally recognised company and trusted brand for 3D printers, it's hard to believe that Ultimaker started with just three men in a garage, working on a side project for a little extra money. The company soon started to grow.

"We found another building, just a few miles down the road, that was abandoned," says Wijnia. "It was owned by the local government and it was meant to be torn down in a plan that was made before 1984! So, all we had to do was make it workable again. From our own expenses, we put in things like heating because it was the middle of the winter. From there it just went on and on."

The results of the new team's incredible work was the original Ultimaker. Hackable without limits, the open source 3D printer DIY kit was easier to assemble than ever before. The Ultimaker was also simpler to use once assembled, featuring an SD card slot for standalone 3D printing as well as an input screen for the user to control the Ultimaker in a more user-friendly way. "I was amazed myself when in these workshops we started giving for the very first model of the Ultimaker, I found out that even artists with no mechanical or software background at all could build the machine themselves and start using it with the right explanation," Wijnia remembers. "I was like, if I can make it work for them too... my god! It's really going to get far. That's really what pushed me in making it simple and making it more accessible to a lot of people."

CONTINUAL LEARNING CURVE

A few more radical changes even let the Ultimaker work at unmatched speeds of 30–300 mm/s while never losing any of its sharp 20-micron resolution. "A few of the things we [learned were] to use proper shafts that were really well-made with the right tolerances," Wijnia continues. "Another great feature of the design was the mechanism that we used, which reduced the weight of the print head itself by such an enormous amount by taking away the feeder motor and putting it on the back. The motors that were moving the axis were bound to the frame, all of them. So you have little weight to move around, and if you have little weight you can move much faster with higher accuracies."



ULTIMAKER 2 SPECIFICATIONS

Layer resolution: up to 20 µm
Build volume: 23 cm × 22.5 cm × 20.5 cm
Ultimaker 2 Go Build Volume: 12 x 12 x 11.5 cm
Ultimaker 2 Extended Build Volume:
23 x 22.5 x 30.5 cm
Position precision X Y Z: 12.5 µm × 12.5 µm × 5 µm
Print speed: 30–300 mm/s
Travel speed: 30–350 mm/s
Filament diameter: 2.85 mm
Nozzle diameter: 0.4 mm
Stand-alone SD-card printing
WiFi printing ready (future upgradeable)
Software: Cura - Official Ultimaker
Print technology: Fused filament fabrication (FFF)
Frame dimension X Y Z:
35.7 cm × 34.2 cm × 38.8 cm (no filament)
Frame dimension X Y Z:
49.2 cm × 34.2 cm × 55.8 cm (with filament)
Operation nozzle temperature: 180-260 °C
Operation heated bed temperature: 50-100 °C
AC input: 100-240 V/-4 A/50–60 Hz/221 watt max.

The printer was a huge success, turning the Ultimaker team into one of the best commercial 3D printer creation companies on the market. Soon after, the Ultimaker Original+ expanded the supported filaments from just PLA to PLA, ABS, and U-PET, and introducing a heated bed for less warping. Fast-forward to today and the Ultimaker 2 introduces three printers ready to use straight out of the box, with sizes for three different build volumes: the mini Ultimaker 2 Go, the Ultimaker 2, and the Ultimaker 2 Extended.

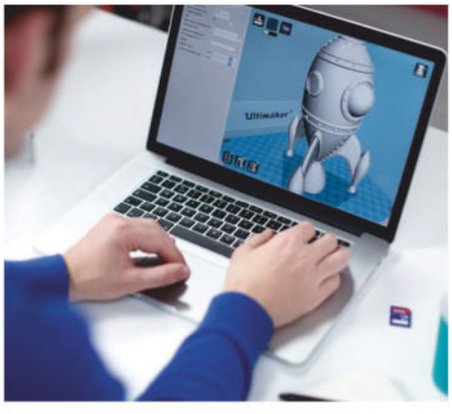
CHANGING THE FUTURE

"It's been a big puzzle, from a great idea to creating a company to growing a company," Wijnia reveals. Despite the surprising growth, the release of four commercial printers and becoming CEO of the company that changed his life, all while being a father to two toddlers, Wijnia remains firmly loyal to staying open source. "China isn't really respecting all those Intellectual Property laws that we have, so we've been cloned," he adds matter-of-factly. "The thing is, if we had everything protected then we probably would have been cloned anyway. The only way to stop them is if I start fighting them, but I don't have the money or time, and I don't want to spend it fighting as I want to spend the money on invention, progression and improvements."

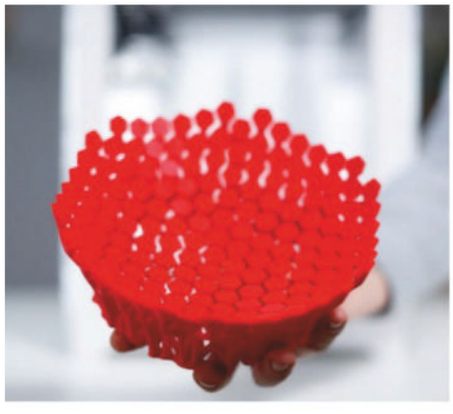
In fact, Wijnia believes there is no need for IP at all. "The whole model behind IP is outdated," he reveals, "and I think what is really important is that the IP stuff was designed in an age that was different to ours. We have so much technological improvement every decade, the 20 years of IP protection feels like a millennium today. It's out of touch, it doesn't fit any more. The only way to speed up the process of getting technology in our hands, so we can work in a real, sustainable way with our environment, is to keep it open source."

SECRET OF SUCCESS

It's been a long time since Wijnia decided to stop working for oil giants to go into 3D printing, but it's with the same principles and determination that the CEO wants to bring Ultimaker forward to inspire others. "What I've learned so far is that every company is basically down to the people that work there – no more, no less," Wijnia concludes. "You can have a great product but if you don't have the right people, you will not get there. I'm so proud of all the people that work with us – they're all Ultimakers. I'm not the company, the co-founders are not the company, the employees are not the company – we are all the company. That's what I'm really focussing on right now – getting the right people and making this the best place you'd like to work. The world is not about money, the world is about having a great day and having great things to do."



Cura is freely available and includes everything you need to prepare a 3D model for 3D printing



With an Ultimaker printer and the Cura software, you can get incredibly detailed prints of your models

CREATING CURA

The free software Cura is well-known as one of the best tools to prepare a model for 3D printing. "A lot of competitors are using it but it originated from our company," confirms Wijnia. "It was by one of our users that bought an Ultimaker to play with at home. He was a programmer. He thought that the interfaces that were available were crappy, so he started designing a new interface that made it more easy to print. We had seen this guy on our forums several times and we started asking him, where are you? It turned out that he lived just down the road, so we said get the hell over here, we want to talk to you! We said what if we employ you and you start working on this program for Ultimaker all day? He said he'd love to and that's how it started. He's one of the great guys that we have. If we hadn't been open, he couldn't have done that and we wouldn't have had Cura."

THE REVOLUTION WILL BE PRINTED

The tide of 3D-printing technology is growing, flooding creative, medical and industrial markets with new ideas and possibilities

3D printing is not new. The concepts of additive manufacturing (AM) and rapid prototyping, which form the basis of this technological movement, have been around for almost three decades. However, the last few years have seen an acceleration in the public's awareness of the technology, as consumer services emerged to offer on-demand 3D printing to the masses. The cost of the technology also dropped enough to enable artists and designers to have a 3D printer in their own studio.

Most current at-home 3D printers work much like Inkjet machines. However, rather than ink they deposit material in successive layers to create a physical object from a digital file. One or more materials may be used (usually plastic, metal, ceramic or glass powder) and several processes exist, namely Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Fuse Deposition Modelling (FDM) and Stereolithography (SLA).

Previously only companies involved in CAD or industrial design work had access to the technology, but in 2008 a spin-off idea from designers at Philips Electronics launched as an online, on-demand, rapid-prototyping service called Shapeways (**www.shapeways.com**). When in 2009 MakerBot (**www.makerbot.com**) launched a DIY printer kit, the Cupcake CNC, the doors were opened for cheaper printers.

MakerBot estimated that in 2012 its devices represented 25 per cent of the overall 3D printer market, while in June of that year Shapeways-printed creations hit the one-million mark. Websites like **www.thingiverse.com** and **www.myminifactory.com** have sprung up, dedicated to the open source sharing of user-created files.

Today, 3D printers are cheaper and more accessible for any user at home than ever before – and the technology is getting more sophisticated to match. Just this March, Carbon3D announced a brand new way to 3D-print using Continuous Liquid Interface Production, a technology 25-100 times faster than other 3D printing methods.

"The biggest development in 3D printing since its invention hasn't been technology-related," explains product designer Samuel Bernier (**www.behance.net/samuelbernier**). "[The people behind] a 3D printer that costs less than €500 EUR (approx $644 USD) to build were the ones that started this revolution."

The history of 3D printing

1984 Charles Hull develops the technology for printing physical 3D objects from digital data, patenting the technique as Stereolithography later in 1986

1986 Hull founds 3D Systems and develops Stereolithography Apparatus, the first commercial 3D-printing machine. This is followed two years later by the publicly available SLA-250

1988 Scott Crump invents Fused Deposition Modeling (FDM) and founds Stratasys a year later. The first FDM-based machine, 3D Modeler, is launched in 1992

1992 DTM sells its first Selective Laser Sintering (SLS) system

2005 Z Corp. launches Spectrum Z510, the first commercially available, high-definition, full-colour 3D printer

2006 RepRap, an open source project aimed at developing a self-replicating 3D printer, is initiated

2008 Objet releases Connex500 rapid-prototyping system, enabling the manufacture of 3D parts using several different materials. Shapeways launches as online 3D printing service

2009 Organovo develops Novogen, the first commercial 3D bioprinter, which prints simple tissues like skin, heart muscle patches and blood vessels. MakerBot ships its first DIY printer, Cupcake CNC

2010 Kor EcoLogic builds Urbee, a car with 3D-printed exterior components

2011 First 3D-printed aircraft is designed and flown by Southampton engineers

2013 Organovo announces delivery of first 3D liver tissue to Key Opinion Leader

2014 Made in Space launches first zero-gravity 3D printer into space

> The people behind a 3D printer that costs less than €500 EUR to build were the ones that started this revolution

Samuel Bernier, industrial designer

NEW WORLDS TO PRINT

Like the spread of 3D printers, the adoption of the technology in areas outside of heavy industrial design has been rapid and varied. "3D printing is making a huge difference in product design," says Fernando Sosa, designer and co-founder of 3D-printing and prototyping service nuPROTO (**http://nuproto.com**). "It's revolutionising the way and the speed at which a product can be designed, tested and made available for purchase. Shoe, car and accessory manufacturers are all adopting this technology to speed up their process and reduce costs."

> "[3D printing] is revolutionising the way and the speed at which a product can be designed, tested and made available"
>
> **Fernando Sosa, co-founder, nuPROTO**

Physical SFX company Artem (**www.artem.com**) bought its first 3D printer back in 2006. "It's now an established part of our in-house pipeline," says CEO and SFX supervisor Mike Kelt. "Projects incorporating 3D printing include the production of certain parts of the *Halo 4* Master Chief suits we made for Microsoft's launch of the videogame. Other projects range from creative animation characters to action props, such as a retractable knife!"

The fashion industry has long embraced new technology and 3D printing has been used by the likes of Dutch designer Iris van Herpen to create elaborate designs. A recent Paris Fashion Week was witness to van Herpen's show 'VOLTAGE', featuring two 3D-printed ensembles. These comprised of an elaborate skirt and cape combination that was created with artist, architect, designer and professor Neri Oxman from MIT's Media Lab and printed by Stratasys. An intricate dress was also designed in collaboration with Austrian architect Julia Koerner and 3D-printed by Materialise. The dress used a brand-new and highly elastic material, TPU 92A1.

Of course, smaller wearable items also lend themselves to additive manufacturing. Jewellery projects are very popular for both studio-based self-fabrication and online routes. "Jewellery designer Jo Hayes Ward visited us [and] said that without 3D printing she would never have been able to produce her intricate gold and silver pieces," says Paul Armand, 3D print and scanning consultant at Inition (**inition.co.uk**)

Using 3D printing with medical projects has also almost become the norm, but is no less miraculous for that. Just a few years ago, doctors and engineers in The Netherlands amazed the world by 3D-printing a prosthetic lower jaw from 33 layers of titanium powder. These were heated, fused together and then coated with bioceramic artificial bone. In the same month researchers at Heriot-Watt University, working in tandem with Roslin Cellab, detailed a method for 3D-printing human embryonic stem cells (hESCs).

With the roots of the technology in CAD, architecture is another area where the industry has grown. For instance, an SLS house prototype was recently created by Softkill Design (**www.softkilldesign.com**). However, everyday proof-of-concepts can also be brought to life: "We developed a joint project with Zaha Hadid Architects, who supplied us with the real CAD data of the Eli & Edythe Broad Art Museum in Michigan," says Armand. "We used that to produce a 3D-printed model and then brought the building to life, adding to its purpose using augmented-reality views."

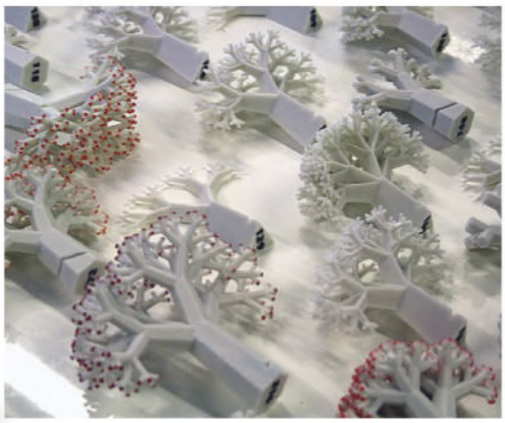
Matryoshka dolls are beautifully profound icons of Russian folk art. With his Mesh Matryoshka design for Soonsalon, Michiel Cornelissen added another layer of meaning: how does one doll get inside another?

Joshua Harker's 3D-printed artwork ready for inspection and delivery to collectors © Joshua Harker

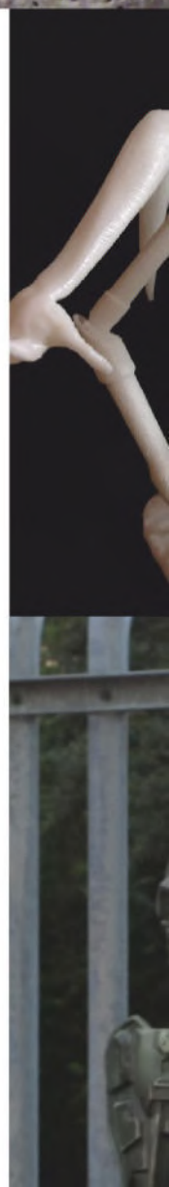
Printing objects with code

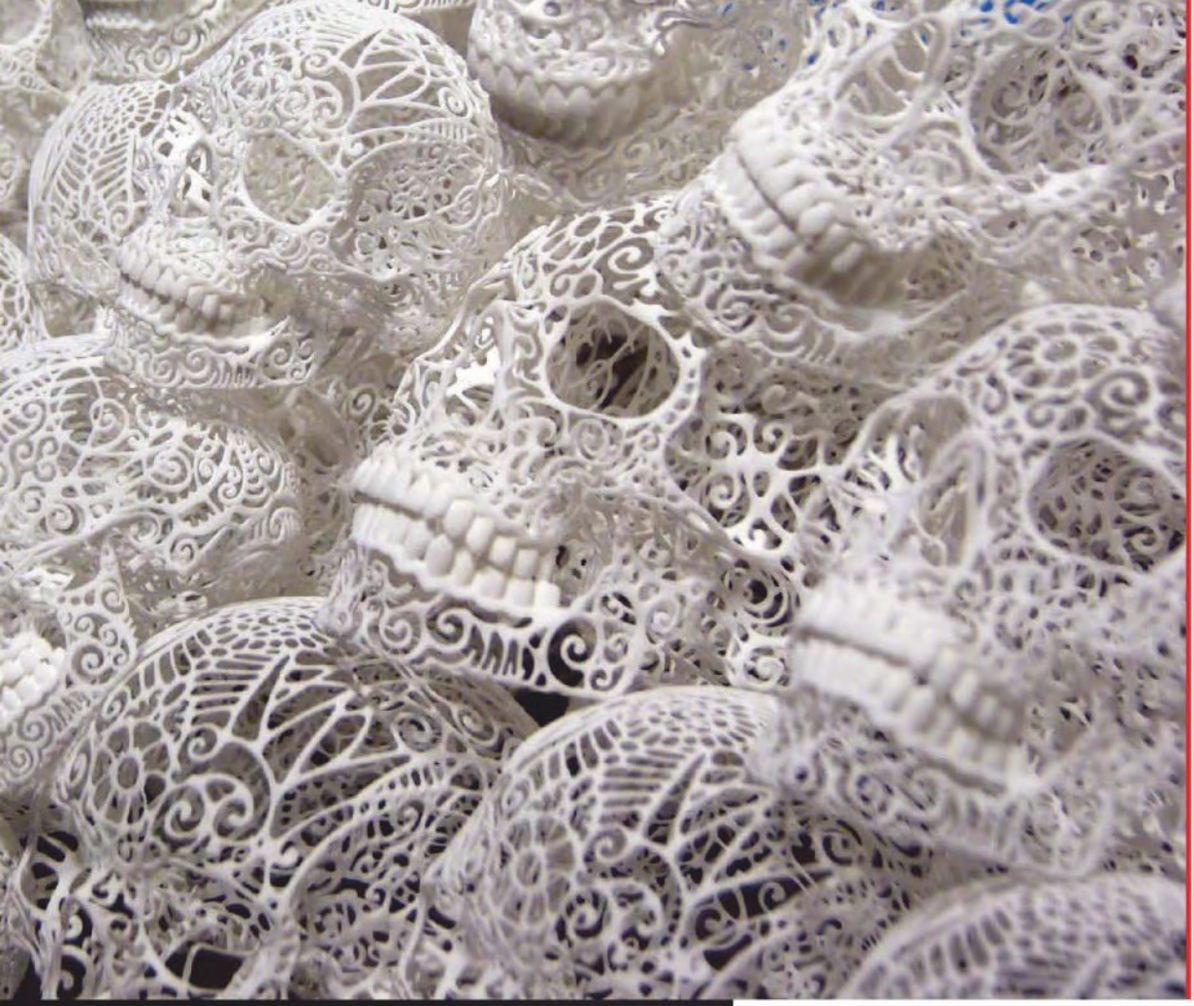
● LONDON-BASED INITION'S first 3D printer was bought back in 2005. "Since this time we've developed many imaginative ways of using the technology and have expanded our range," says 3D print and scanning consultant Paul Armand. "We've gone from printing parts directly from clients' CAD data to projects where we're developing code to [effectively] grow 3D-printable objects into a type of physical 3D infographic."

An example of this is *People Wood*, Inition's work with design practice Something & Son. The latter had been commissioned by a Hackney charity to create a sculpture for a new community centre. Inition created a miniature forest of over 400 3D-printed trees, each of which were developed according to data that was crowd-sourced from online questionnaires. Factors such as the thickness of the trunks and the number of branches represented an individual's sense of community. "It illustrates how 3D printing has emerged from predominantly engineering environments to bespoke creative implementations," observes Armand.



For *People Wood*, a miniature forest of over 400 individually designed, 3D-printed trees was developed using data crowd-sourced from online questionnaires
© Inition





Size matters!

This is the Dimension 1200es Series 3D printer at Artem (top), launched in 2008. In contrast, the UP! Mini printer from PP3DP (bottom) was launched in 2012 for desktops

Cyborg Spider
© Fernando Sosa

Halo 4
© Artem

ADDITIVE MANUFACTURING FOR EVERYONE

"The reduction of the cost of developing products has brought product design down to the masses," explains Fernando Sosa. "This is why you can see tons of 3D-printed objects [seeking crowdfunding] on Kickstarter and Indiegogo.

"My phone cases with money clips are a perfect example," he continues. "I've sold hundreds of these via Shapeways. I also received much-appreciated feedback to make the design better."

Sculptor and artist Joshua Harker (**www.joshharker.com**) holds the record for the most-funded sculpture project in the history of Kickstarter. "For ten years I owned a design and development studio with very high-end PolyJet 3D printers, a CNC machine shop, a vacuum-/pressure-casting system, a dozen employees and so on," he recalls. "My overheads were [around] $60,000 USD per month. I sold my partnership in 2008 and now run at nearly $0.00 US – aside from electricity, workstation and software upgrades. I outsource printing on an as-needed basis, mostly through Shapeways. I keep very little stock and have more time to create rather than produce. Other than having to wait for my pieces to get printed and shipped, it's hard to argue with the benefits."

"Using an external bureau gives you the best all-round choice, as well as leaving the overhead, maintenance and material issues to others," reveals Artem's Mike Kelt. "However, the cost of machines is always lowering and coming within the realms of small-scale users, providing you don't want the latest or most accurate printer. You have to think about the life span of the machine, as upgrading is not really an option. You'd only throw it away and buy a better one after a few years."

Choosing the right printer and material depends on the type of part you want to create. "For complex and organic shapes, EOS has very good powder-based printers, while for affordable and functional objects MakerBots are just great. Also, ABS is strong, flexible and colourful," adds Samuel Bernier. Kelt is also a fan: "ABS is a hard and durable material, which also lends itself to the processes that follow, such as sanding, gluing and painting," he says.

"If you're looking to produce small, less-complex components made in plastic, then a desktop printer could be the most suitable," says Paul Armand. "It's for these types of projects that we would use our 3DTouch printer from 3D Systems. This heats thermoplastic material through the extruder applying layers according to the X and Y co-ordinates. This builds a solid 3D object. It's low-cost and you won't achieve the resolution of professional types of 3D printers, such as powder- or resin-based systems. If you're looking to do rapid prototyping professionally, the ZPrinter and ProJet 3D printers offer a lot more in terms of colour and high resolution."

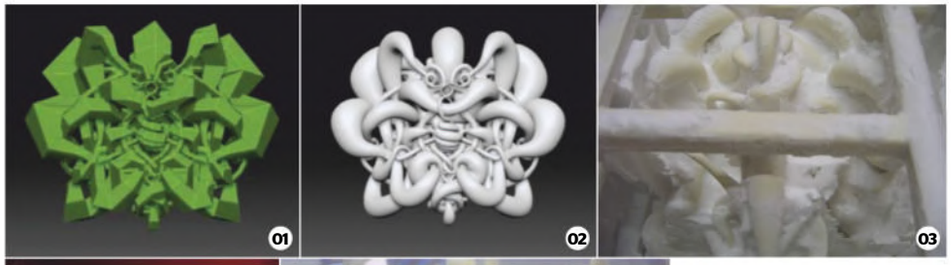
Metallic masterpieces

Joshua Harker's abstract and highly complex series 'Tangle Sculptures' began life in ZBrush, but some of the pieces also ended up in bronze using a 3D printing process.

"*Permutation Prime* was the very first tangle I made that was printable and *Dynamic Transcendental Migration* was the first tangle that was cast in bronze," says Harker. "Those two pieces tested out the pipeline for creating shapes that were previously impossible. [They were also] the first pieces in history to break the design and manufacturing possibility threshold in their respective materials. This was a perfect storm of software, 3D printing technology, material engineering and vision."

Here we show the step-by-step process for Permutation Prime. More examples can be found at **www.joshharker.com**.

Finished *Permutation Prime* after final patina and polishing © VOXELJET



01 The *Permutation Prime* tangle at the very early stages of the design process

02 The finished tangle render as seen in ZBrush

03 The 3D-printed pattern for bronze-casting, ready for removal from the printer

04 The 3D-printed model being removed from the printer

05 The powder support material being removed using compressed air

06 The model gated, vented and ready for the investment-moulding process

07 Hot investment mould of the tangle after burn-out and ready for casting

08 The molten bronze being cast into the investment mould under a vacuum

09 The bronze casting after removal from the investment mould, ready for sprue, gates and runners to be removed

10 The casting after cleaning and sandblasting, ready for patina and polishing

Images 01-03 © Joshua Harker | Images 05-09 © VOXELJET

Inition was approached by creative design agency ATYP to provide a 3D scan and 3D print of musician Si Begg's head, for the launch of his new album © Inition

THE BEST SOFTWARE FOR PRINTING IN 3D

The majority of software packages used in the 3D printing process output in the industry-standard STL file format. Some more basic tools like Blender, Autodesk 123D and Trimble SketchUp are free, but even with commercial CAD and 3D apps like SolidWorks, Rhino and ZBrush, the process isn't always confined to one application. For example, Artem mostly uses SolidWorks, though ZBrush and Maya are also used in the pipeline.

"I find that Rhino is usually pretty good at creating STLs, especially when I take the time to create a nice clean model," says Michiel Cornelissen (**www.michielcornelissen.com**). For his Zesch and Mesh Matryoshkas designs Cornelissen also used the generative Rhino plug-in Grasshopper. "In both cases the model was built up almost entirely in a parametric definition in Grasshopper," explains Cornelissen. "For Zesch, it [enabled me to] create the interlocking elements, while at the same time being able to tweak the proportions. For the Mesh Matryoshkas design, [the plug-in] helped me make and optimise the mesh pattern interactively, [as well as] play with the proportions of the differently sized dolls and so on."

"I use SolidWorks for hard modelling and pieces that require engineering considerations, whereas ZBrush is best for organic sculptures," says Joshua Harker. "SolidWorks has always been well suited to

Inition's work with Fitzwilliam Museum in Cambridge and Feathercast has shown that 3D printing and scanning can generate much-needed revenue for museums
© Inition

3D printing, but ZBrush not so much – though the experience has become better over the last few years."

"I use SolidWorks, since I come from a technical background," explains Samuel Bernier. "I need my parts to be modified easily by parameters and they often need to be precise. I rarely require organic forms. Also, SolidWorks makes solid parts, which are almost always ready for printing in 3D, while a lot of things can go wrong with surface modelling."

nuPROTO's Fernando Sosa and Mike Bauerlein both have backgrounds in 3D animation, so are most comfortable when modelling in Maya and ZBrush. "However, 3D printing requires a watertight model with non-manifold faces and clean geometry," explains Sosa. "We have used a lot of programs to clean up our geometry and our clients' geometry. In some cases we have used Modo to Boolean and clean up geometry. We have also used MeshLab and Blender to check for holes and convert OBJs into STLs – a feature not available in Maya. We've also integrated Magics from Materialise to create watertight shells around complicated objects."

Materialise Magics and NetFabb are STL-correction software packages used to correct inverted normals, fill in the gaps in body meshes, as well as scale, modify and align bodies and parts ready for print.

"Netfabb and MeshLab will help validate and even repair your files in preparation for printing," says Joshua Harker. "There's a limit to what they can do, but they're a good start – and they're free."

> "Rhino is pretty good at creating STLs, especially when I take the time to create a nice clean model"
>
> **Michiel Cornelissen,** designer

Crooked Cairn detail from Joshua Harker's *Anatomica di Revolutis*, in 3D-printed polyamide
© Joshua Harker

A 3D-printed scale model of The Eli & Edythe Broad Art Museum, designed by Zaha Hadid Architects, was used to showcase new augmented reality tech
© Inition

Samuel Bernier believes we could soon see printers available for as little as $129 US

> "Printers will inevitably get better, cheaper and faster. The size of machines is limited at present, but I'm sure that will change dramatically"
>
> **Mike Kelt, Artem CEO and SFX supervisor**

THE FABRICATED FUTURE

Given the trajectory the technology has taken so far, there's no doubt that 3D printing is set to accelerate. Paul Armand suggests that we could see an even larger variety of desktop printers appearing on the market, other than those based on FDM technology, "such as the Formlabs Form 1 printer", he says. "However, larger printing manufacturers hold a lot of IP for various printing processes and techniques, so it's difficult to speculate what exactly will arrive next. [Certainly], the resolution will continue to be improved, as will the choice of materials and colours."

"Printers will inevitably get better, cheaper and faster," agrees Mike Kelt. "The size of machines is limited at present, but I'm sure that will change dramatically. The materials will advance and no doubt it will be possible to collect parts for certain manufactured items, such as spare car parts, which could be printed locally rather than held in a huge stock warehouse."

Michiel Cornelissen agrees: "Larger products like furniture will become much cheaper to print in 3D, due to the introduction of large, low-resolution printers comparable to what Dirk van der Kooij is using currently (**www.dirkvanderkooij.nl**)." He adds that 3D printers are on the way to becoming a standard household item, comparable to the microwave in the 1970s.

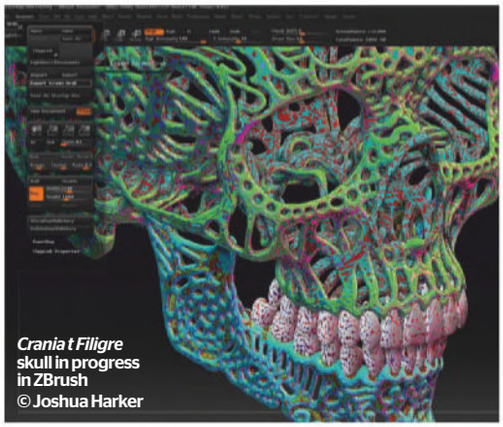
"For FDM printing at least, we can expect 3D printers that cost €100 EUR (around $129 USD)," adds Samuel Bernier. "However, I'm not sure that this will be a good thing. I don't think that everybody should own a 3D printer. A lot of people would use it to produce useless junk."

"3D printing might contribute to the throw-away, short-attention-span culture that's already around," agrees Cornelissen. "Need something? Print it, now. Don't like it? Throw it away, print something else..."

This highlights the darker side to this revolution, compounded with a recent site aiming to host printable gun parts. The same party is behind a new site that provides access to blueprints of third party objects, currently mainly firearms-related. Many of the designers we spoke to were angry at the former and dismissive of the latter, pointing out that Thingiverse already provides a way of sharing designs.

"The good side of all this is that it forces the dialogue and a consideration for what we can ethically do with this technology, [as well as] the ways and means for controlling and protecting IP," observes Joshua Harker.

Harker also feels that the increased adoption of the technology will involve changes to more than just print: "More people will have a measurable percentage of 3D-printed parts in their body, from bony implants to 3D-printed tissues and organs..." he predicts. "Batteries and electronics will be integrally printable into models. Pharmaceuticals may be printed and dispensed from vending machines, using a special prescription card. Capitalism is in line to becoming a better-balanced system, due to the shift from a consumer-centric to a more participatory model."



Crania t Filigre skull in progress in ZBrush
© Joshua Harker

Top tips for printing watertight models

- A file designed to simply be viewed on a 2D medium, such as a monitor, is not up to the task of existing in true 3D. It will be full of holes, where parts don't meet or line up.
- Design from the start with 3D printing in mind. It can take a long time to go back to an existing drawing and attempt to modify it for a 3D printer.
- Always model from solid functions.
- Make sure you don't have a double surface – your model should be like an air bubble, just a skin.
- Solid modelling packages such as SolidWorks and CATIA naturally create cleaner 3D data than surface-modelling packages like Trimble SketchUp.
- Remember, you can't print a plane that has no discernable dimension. Everything has to have volume and cannot have any holes in the mesh.
- You can edit your STL by using a software like Netfabb.
- Perform a very close inspection of the whole model in the software of your choice. Get inside and outside the model, invert it, rotate it and select its faces.

3D Make & Print would like to thank Joshua Harker, Samuel Bernier, Mike Kelt, Paul Armand and Fernando Sosa for their contributions to this article.

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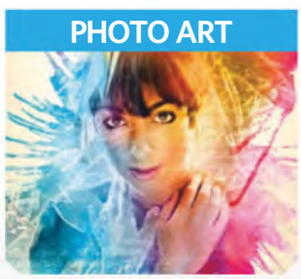

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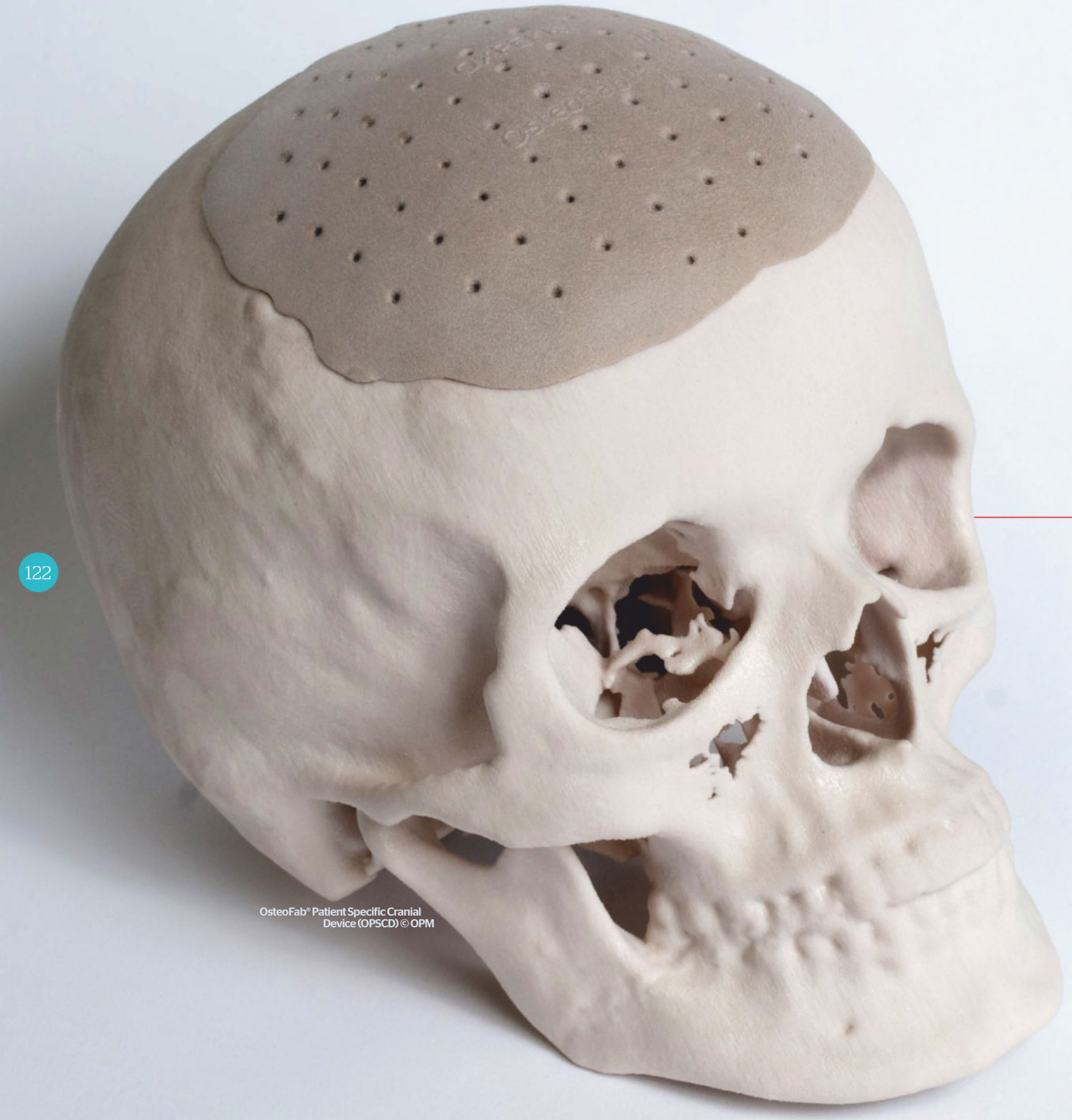


OsteoFab® Patient Specific Cranial Device (OPSCD) © OPM

HOW 3D PRINTING WILL SAVE YOUR LIFE

Dr Anthony Atala
Director of the Wake Forest Institute for Regenerative Medicine / USA

Professor Lee Cronin
Regius Chair of Chemistry / UK

Dr Andrew Dawood
Co-founder of Dawood & Tanner, Digits2Widgets and Cavendish Imaging / UK

Scott DeFelice
CEO of Oxford Performance Materials / USA

Joseph DeRisi
DeRisi Lab / USA

Mick Ebeling
CEO and co-founder of Not Impossible Labs / USA

Elliot Kotek
Content chief and co-founder of Not Impossible Labs / USA

Thomas Most
Prosthetic-orthotic CAD/3D printing specialist / USA

Suman Mulumudi
CEO of StratoScientific Inc, inventor / USA

Professor Raphael Olszewski
Surgeon and head of the university's oral and maxillofacial surgery research lab (OMFS Lab, UCL) / Belgium

Michael Renard
Executive vice president of Organovo / USA

Whitney Sample
Nemours / Alfred I. duPont Hospital for Children / USA

Professor James Yoo
MD, PhD, Professor at the Wake Forest Institute for Regenerative Medicine / USA

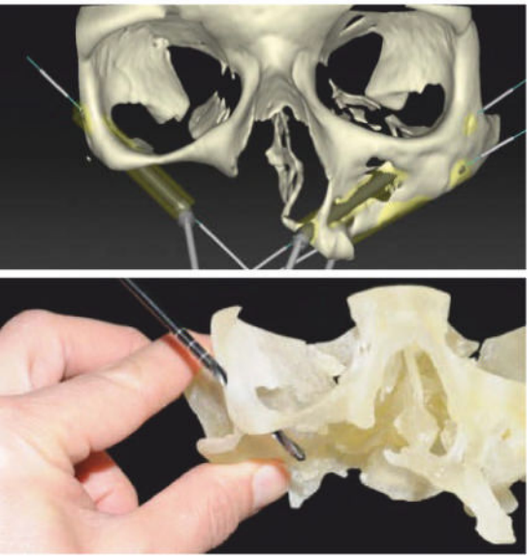
From prosthetic limbs to fully functional organs, we look at how 3D printing is revolutionising more than just the manufacturing industry

3D printing will be the next industrial revolution. With the technology becoming cheaper and more accessible over the last few years, this is a future many have been quick to predict. What if, though, we could use 3D printers not just to revolutionise the manufacturing, but to save lives as well?

Being able to print out custom-made artificial limbs, prosthetic noses and even human organs may seem like science fiction, but by utilising 3D printing for applications within the medical industry, this is fast becoming part of our everyday reality. At the end of 2013, California-based company Not Impossible used 3D printers to produce hands and arms for amputees in Sudan, giving a teenager the ability to feed himself for the first time since war had left him disabled at 14. In January this year, 3D bioprinting company Organovo launched the world's first printed organ product – a functional slice of human liver.

"November 3 2013 – remember that date," begins prosthetic-orthotic CAD and 3D printing specialist Thomas Most. "It was huge, because it was then that the UK's Fripp Design and Research made the first successful 3D-printed silicone. People have been trying to do that for 15 years and they did it. I felt the first piece in my hand and thought 'holy cow, this is huge'.

"Say somebody was missing an eye from cancer or trauma," continues Most. "These days prosthetics have to be moulded and cast in silicone, but once the machines are available, you could digitally sculpt or scan their face and then you could send it as a file directly to the silicone printer. It would be made without mould or casts so the cost would come down dramatically and save a huge amount of time." Other materials have huge advantages too. Most explains that joints and even spinal surfaces made out of titanium could be produced not only to be more lightweight, but also in such a way that enables the surrounding bone tissue to grow into the device so that it almost becomes part of a patient's body. "It's no longer just a titanium piece that has been machined to be the same as any other – a foreign object jammed into the top of your femur," beams Most. "Now, your femur grows around it and encompasses it so that it's even stronger – it's a part of you."



3D modelling by Dr Veronique Sauret, Cavendish Imaging, used to plan an advanced implant reconstruction surgery for a patient missing half their upper jaw and all of their teeth in 2013

BUILDING THE ARTIFICIAL LIMBS OF THE FUTURE

The biggest challenge to overcome now is education. According to Most, as many people as possible need to know about the incredible things medical 3D printing can do. "As of January this year in the States, all the orthotics and prosthetics schools – none of them were teaching CAD or anything you need to know in order to manipulate the file so that it's printable, which blows my mind," he tells us. "As far as I'm concerned, they're missing the boat. I'm talking about being able to make a custom artificial device to replace a body part that's a better fit from the get go, and actually enables you to treat patients faster. I predict that in three to five years, if they don't get on board with some of the scanning and printing technology, it's going to be taken away from them by other franchises."

It's easy to get caught up in the figures – the fact that a 3D-printed limb can cost thousands of dollars less than lower-quality alternatives is really exciting, and a winning argument against 3D-printing naysayers. Yet such cold, statistical facts can get in the way of the simple human factor that makes these achievements truly newsworthy – 3D printing can change a life, forever.

It was in war-torn south Sudan that Daniel, a 14-year-old who considered his life no longer worth living after losing both arms to a bomb, found himself the focus of Not Impossible Labs founder Mick Ebeling's attention. The California research firm aims to provide low-cost, open source solutions to previously insurmountable healthcare issues. In this instance, by using simple, consumer-grade MakerBot Replicator 2 desktop printers, Not Impossible was able to print out the parts to produce a full prosthetic arm, on-site, in less than six hours. With no need for expensive medical treatment or to walk miles in search of a specialist prosthetics centre, Daniel was able to feed himself for the first time in two years.

Following the success of Daniel's new arm, Ebeling and the team set up the world's first 3D printing prosthetic lab and training facility to teach others to print and assemble the 3D prostheses. A little more than a week after Not Impossible Labs had been back on US soil, four more arms had already been built. "We're hopeful that people in other regions of Africa, as well as other continents around the globe, will utilise the power of this new technology for similar beginnings," Ebeling explains. "We believe that Daniel's story will ignite a global campaign. The sharing of the prostheses' specifications, which Not Impossible will provide free and open source, will enable any person in need, anywhere in the world, to use technology for its best purpose: restoring humanity."

Like Not Impossible, the team at the non-profit Nemours Foundation was also inspired to use 3D printing by a child who needed help that existing methods could not provide. "It started kind of by accident," begins Whitney Sample, research designer at Nemours/Alfred I. duPont Hospital for Children. "Prior to the 3D printer we were still designing devices for children with disabilities, but used other fabrication manufacturing tools. One of the advantages of 3D printing from the start was the speed of going from an idea to a prototype, plus the accuracy of it. With most other machining processes there is a fair amount of mechanical skill involved to get good results. That's bypassed with the 3D printing process because you're going straight from CAD to printed model."

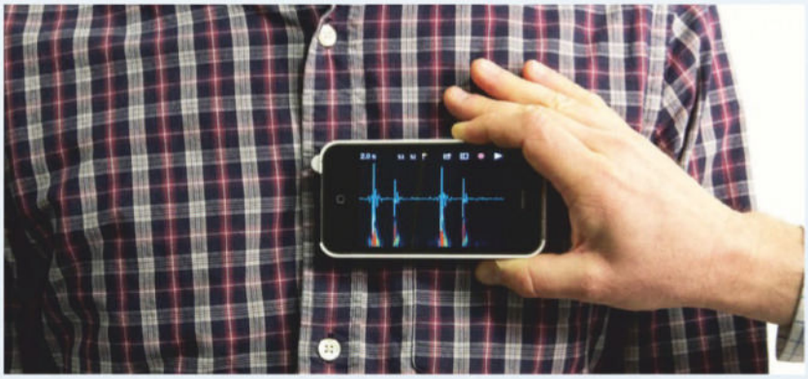
The patient that changed everything was two-year-old Emma, born with arthrogryposis multiplex congenita, or AMC, a non-progressive condition that causes stiff joints and under-developed muscles. With the help of WREX (Wilmington Robotic Exoskeleton) – a device that Sample and Tariq Rahman, head of pediatric engineering and research at Nemours, had developed – she would be able to lift her arms. The problem was that WREX had been created for wheelchair users, while Emma could walk.

"We needed to make something lighter and much more adaptable to her lifestyle, and it just so happened that we had a Stratasys 3D printer right around that same time," Sample remembers. "The fact that we could make WREX lighter and could replace parts quickly was amazing. We could constantly make design adjustments and test them out on Emma for the best comfort and mobility." For Sample, a future in which equipment for children like Emma can be printed at home, with parts replaced and customised as they grow,

iPhone to stethoscope

After building a Thing-O-Matic with his class at school, student Suman Mulumudi spotted a major gap in modern medicine. Inspired by his father, a cardiologist, he designed the Steth IO, a device that enables a smartphone to work as an audio-visual stethoscope, and 3D-printed it. Now he's started his own company, StratoScientific Inc, to design more innovative products. "One of the most empowering parts of 3D printing is that it opens up your mind to thinking in different ways," explains Mulumudi. "Without realising it, I believe we often limit our thought process by what we think we can produce. The future of healthcare lies in its ability to be individualised to suit the patient, and for the first time this is truly possible with medical 3D printing."

The Steth IO prototype and how it would work as very accessible stethoscope



Daniel and a friend, showcasing their new 3D-printed artificial arms. The prosthetic arms enabled Daniel to feed himself for the first time since he lost his arm two years earlier

isn't too far off. "Humans like custom-everything," he explains. "Look at your iPhone case. People want the same iPhone, yet everybody wants a different case. Throw into the mix disabled people, who actually need custom-everything as unique adaptations to deal with their disability – it's a perfect match for 3D printing. All you have to do is make adjustments to a file. Alternatives like injection moulding cost close to $10,000 to mould for one part and that's not even a complex part. You can get printers for a couple hundred dollars now, so it's just a matter of time before the rise of this new way of life. It's inevitable."

GOING DEEPER

Where we're likely to start seeing the biggest shifts towards universal adoption of the technology is dentistry. There are already several dentistry-only 3D printers on the market, offering the ability to work with materials such as porcelain, metals, soft plastics and even wax. "Of course, dentists tend to have a lot of extra money to buy all the tools they need," Sample remarks, "and with 3D printing, they can go straight from the MRI scan to making a retainer, a crown or any type of mouthpiece. Not only can treatments be specifically designed for each mouth, but physical positives and casts of a patient's mouth don't need to take up storage space any longer. Everything is digital."

Dr Andrew Dawood, dental implant lead at Dawood & Tanner and specialist in prosthodontics and periodontics, knows these advantages better than most – he's been using 3D printing in dental implant treatments at his London practice since 1999. "I can not contemplate medicine and dentistry without 3D imaging," Dr Dawood states. "Having a 3D printer is only a part of the battle though. There is no point in having the hardware if you don't have access to the design talent and software." Considered a pioneer in the field, Dr Dawood has used 3D printing for a number of major developments, such as during the planning stages of reconstructive surgery for a patient who had lost his jaw, teeth and gums following a shotgun injury during a robbery. The surgery was the first of its kind and, by using 3D printing to create a replica of the patient's jaw beforehand, everything from the bone graft to be taken from the patient's shoulder to the position of replacement teeth could be extensively pre-planned, greatly reducing surgery time and risk.

Perhaps the most famous example of Dr Dawood's work, however, is with Eric Moger, a man left disfigured after emergency surgery to remove a tennis ball-sized tumour growing beneath the skin on his face. As traditional reconstructive surgery was not an option due to the chemotherapy and radiotherapy Moger was receiving, 3D software was used to model the contours of a facial and oral prosthesis that could be used to restore the shape of his face. This model was then 3D-printed along with implants to anchor the prosthesis in place.

"3D printing and scanning helped us to streamline treatment, making it faster and less invasive, even enabling us to carry out multiple procedures in a single step instead of many," explains Dawood. "I am pleased that this work has highlighted the issues faced by patients with these problems – patients who otherwise appear to receive little attention and can feel unable to leave their homes. Mr Moger is certainly an inspirational individual." Following the treatment, Moger was able to ingest food and water regularly for the first time since he had undergone the initial surgery.

Medical 3D printing isn't based just around external work, however. "If someone gets in a car accident or develops a tumour, sometimes they essentially treat that by taking a large chunk of your skull," begins CEO of Oxford Performance Materials, Scott DeFelice. "However, if they do that, sometimes they try to put it back in but it just ends up not living." Like Dr Dawood and the rest of the team behind Eric Moger's incredible transformation, DeFelice also uses 3D printing to help patients with defects – in this case, by 3D printing a replacement bone: a piece of their skull. Originally, the company had started doing business by selling a proprietary polymer that was structurally similar to bone. Then, in the mid-2000s, DeFelice came across an article from a surgeon discussing the huge advantages 3D printing would offer with implantable materials.

"I went to our technical director and I asked whether we could simply print our stuff. That's how we started," continues DeFelice. "When we first came to 3D printing, people would be taking a big chunk of plastic, aluminium or titanium and machining it. You'd end up with things that didn't quite fit right and you couldn't even make something that was that complex, or it would take very long or be too expensive. All of a sudden, 3D printing comes along and we can get a CAT scan for a patient, design it to fit right into that person's defect, print it up with a bunch of other implants

We can make things that are anatomically precise for a cost that's affordable and in a material that fits

Scott DeFelice, CEO of Oxford Performance Materials

every week and ship it to the customer within five days of the order." With their new 3D-printed material called OsteoFab, Oxford Performance Materials has now been working on designing custom-fit replacement skulls for critical surgical procedures all over the world, including a surgery where 75 per cent of a patient's skull was replaced. "We can make things that are really anatomically precise for a cost that's affordable and in a material that fits," tells DeFelice. "That wouldn't be possible without 3D printing."

Incredibly, even something as seemingly irreplaceable as human skin could soon be 3D-printed. A few years ago, James Yoo, professor at the Wake Forest Institute for Regenerative Medicine, began designing a printer potentially capable of bioprinting skin directly onto a patient in need, such as a burn victim. The printer, which is now reportedly set to be used in clinical trials within three to four years, could completely change the lives of those with wounds that would not heal well, or those with a supply of skin too limited for a graft that needs to be taken from other areas of their body. Yoo has also been developing another printer – a hybrid printer that could print implantable fake human cartilage, which would revolutionise medicine, considering doctors are unable to fully regenerate cartilage today. "The idea behind the hybrid system was to print a durable construct made of gels, which promote cell growth, as well as synthetic materials, which provide strength," he explains.

The engineered cartilage would not only be a faster, cheaper solution, it would also encourage cells to integrate into surrounding tissue, letting new cartilage fill the defect, making it even stronger than before. "After eight weeks of implantation, the constructs appeared to have developed the structures and properties that are typical of elastic cartilage, demonstrating their potential for insertion into a patient," Yoo reveals, telling us that though impressive, this is, in fact, just the beginning of the research the team has undertaken. "Based on this concept, we have since developed a more sophisticated robotic 3D system that has been used to print cells such as muscle, cartilage and kidney."

PRINTING ORGANS

"Basically, printing technology enables us to scale up the production of engineered organs," explains Anthony Atala, director at the Wake Forest Institute. Though even he agrees that it sounds like something from science fiction, Atala is a firm believer in the fact that 3D-printing complex organs will truly become a reality, though not for several decades. "It enables a personalised cure by using data from a patient's CT scans to actually design a replacement organ or tissue," he tells us, explaining that the technology would not only enable the precise placement of each cell, but since bioprinted organs could be made using the patients' own stem cells or biopsies, the organs would not be rejected by their immune systems.

If this technology could be fully realised, 3D printing human organs would be responsible for saving thousands of lives a year – eighteen people die waiting for an organ transplant every day and many others lose their lives before they even get onto a transplant list. With an ever-growing population, the number of people who need a transplant increases every year.

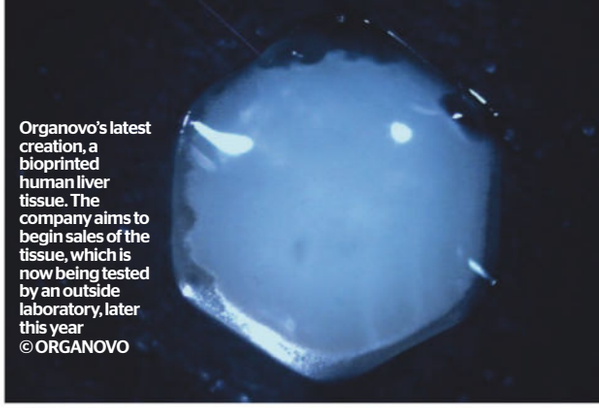
For Organovo, the first publicly traded bioprinting company, solving this problem is the ultimate aim. "Our goal is to recapitulate native biology," affirms Mike Renard, executive vice president of commercial operations. "We want to make a difference in people's lives, to restore and regenerate health." Using their own NovoGen MMX bioprinter, the team develops bio-inks, or multi-cellular mixtures created from cells of any source, which are then dispensed from the printer layer by layer with the help of a computer-programmed script. After being incubated for 48 hours or more to allow it to mature, the tissue is then ready. If everything goes according to plan, it will achieve the form and function of the living version of itself. Bio-inert hydrogel components may even be used like 3D printing supports for the tissues as they are built up vertically to ensure correct three-dimensional shapes.

In 2012, Organovo partnered with Autodesk Research to develop 3D bioprinting software to aid the process. Two years later, months ahead of the intended April 2014 release, the team delivered the company's first future product – slivers of functional bioprinted liver – to an external lab for experimentation. Later this year, Organovo aims to begin commercial sales.

"The intended use is for medical research and drug discovery," continues Renard. "It can give scientists in the laboratory a new model to conduct testing and analysis." In fact, using the bioprinted liver tissue to test how the real organ could process and react to new drugs will greatly improve the speed, predictability and expense of drug discovery and development, which on average costs 1.2 billion dollars and takes twelve years to develop with methods used today. Of course, this is also a major step towards Organovo's long-term goal of producing full organs. With the technology they've developed, printing an average-sized liver would only take ten days. The team is working towards prints as fast as three hours. It's a revolutionary concept, and one that could truly change the world.

One of the advantages from the start was the speed of going from an idea to a prototype, plus the accuracy

Whitney Sample, Nemours/Alfred I. duPont Hospital for Children



Organovo's latest creation, a bioprinted human liver tissue. The company aims to begin sales of the tissue, which is now being tested by an outside laboratory, later this year
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The Novogen MMX Bioprinter®
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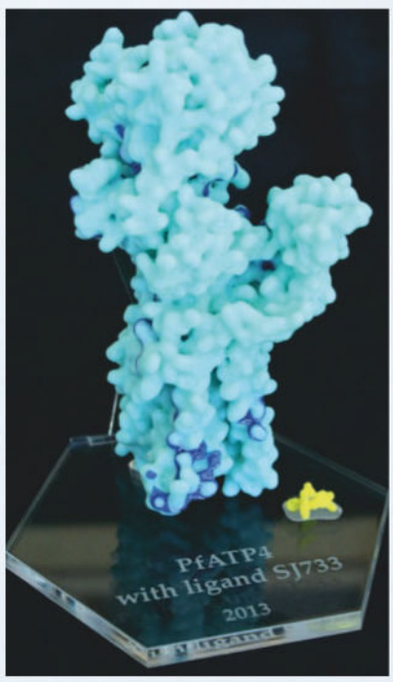
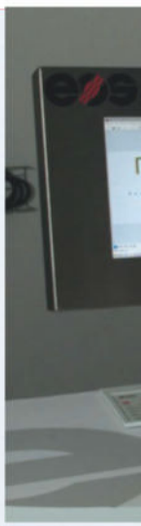
Printers in the lab

Already, printers are enabling researchers to print the exact tools that they need very cheaply compared with older methods, and for biochemist Joseph DeRisi, allowing scientists to learn CAD and 3D printing for their work is crucial. "3D printing is now an integral part of our everyday laboratory work," he explains. "We use Solidworks and Autocad within the lab. Learning CAD is fine for scientists – it's a lot easier than biochemistry! We make parts for pretty much everything you can imagine, everything from custom slides on microscopes to microscope parts and adaptors." The files for the equipment produced by DeRisi and the scientists at the lab are currently available to download at **http://derisilab.ucsf.edu/index.php?page=3D**.



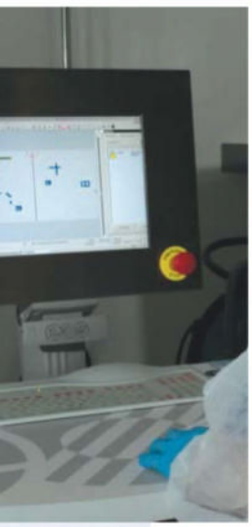
Protein-drug interactions made tangible by 3D printing: model rendered in Chimera, printed on Dimension's uPrint



The process of creating a patient-specific cranial implant device from OsteoFab, including the printer while lasering and the breakout of the skull implant. The medical devices are derived directly from the patient's CT Scan or MRI file for a perfect anatomical fit, and can be shipped to the customer within five days of the order being placed

Improving surgery

Doctors in Belgium have saved hours in traditional facial surgical procedures by scanning the contours of patients' bones, then 3D-printing full-size models to use as a surgical guide. As the model is such an exact replica of the patient, surgeons can also use it to pre-plan, shaping the metal inserts that fit along residual bone during reconstructive surgery, removing the need for trial and error during surgery itself. Impressively, this is all done using paper 3D-printing. "Paper 3D-printing is the only ecological technology on the market, involving only a biodegradable laminated paper and eco-friendly adhesive from Mcor Technologies," notes maxillofacial and oral surgeon professor Raphael Olszewski. Affordable and biologically friendly, the technique could be a powerful alternative to the expensive neuro-navigation systems that currently ensure accuracy in surgery.



Professor Lee Cronin, Regius chair of chemistry at the University of Glasgow, believes 3D printers could one day go even further. They could be used to perform chemical reactions to make new molecules for applications such as drug discovery, or there's the possibility of a personal medicine fabricator, which could be used to print medicines at home. "What it actually should be called," says Cronin, "is a matter manipulator, because you have to put stuff in and you alter that stuff – there's no magic to it, just chemistry." The idea came to him after an architecture conference a few years ago, where he heard a presentation on 3D printing for new architectural designs. Cronin then thought it might be interesting to use the technology to work on chemical reactions in the lab; he and his team have begun to both modify existing printers and create their own to do this.

Their printers essentially have two roles. The first is as a classic 3D printer for plastic objects – the beakers and test tubes needed for reactions. The second involves the printer using its X, Y and Z-axis functionality not to print plastics, but to handle liquids, moving chemicals into the plastic devices created. In principle, this would mean that as long as you knew what inputs you have used and the order in which they are mixed, it would be possible for people to simply share that code with each other to reproduce the same molecules. "Say you have two labs, one in Australia and one in America," he explains, "and the one in Australia has just learned to make a new molecule which is really tricky to make. If there was a robotic system that understood all this code and they gave that code to the group in the US, maybe the group in the US could reproduce that molecule much more effectively than other routes such as trial and error." Eventually, this could mean that being able to print something such as a drug will be possible in the next 20 to 30 years.

"The other thing to bear in mind," Cronin adds, "is that one day, if this does catch on and is useful – not even as something in your house but for when you go to a drugstore – is that a lot of drugs aren't made forever. When an old drug is replaced by a newer, presumably more expensive drug, you don't get access to the other one. What this means is that people could access 'out of print' drugs, which may be a way it can become more economically viable to use these machines."

Cronin knows what a huge undertaking this is, but the team is aiming for a proof of principle to demonstrate what is possible and start a serious discussion. "One day, we may even think about programming chemistry, using a chemical HTML and standardised scripts, but it's important now to start debating just how safe it would be, the consequences of potential misuse and the new economic models that may emerge from the ability to fabricate your own things," he concludes. "This is not science fiction. It's going to happen."

BEST 3D PRINTERS TESTED

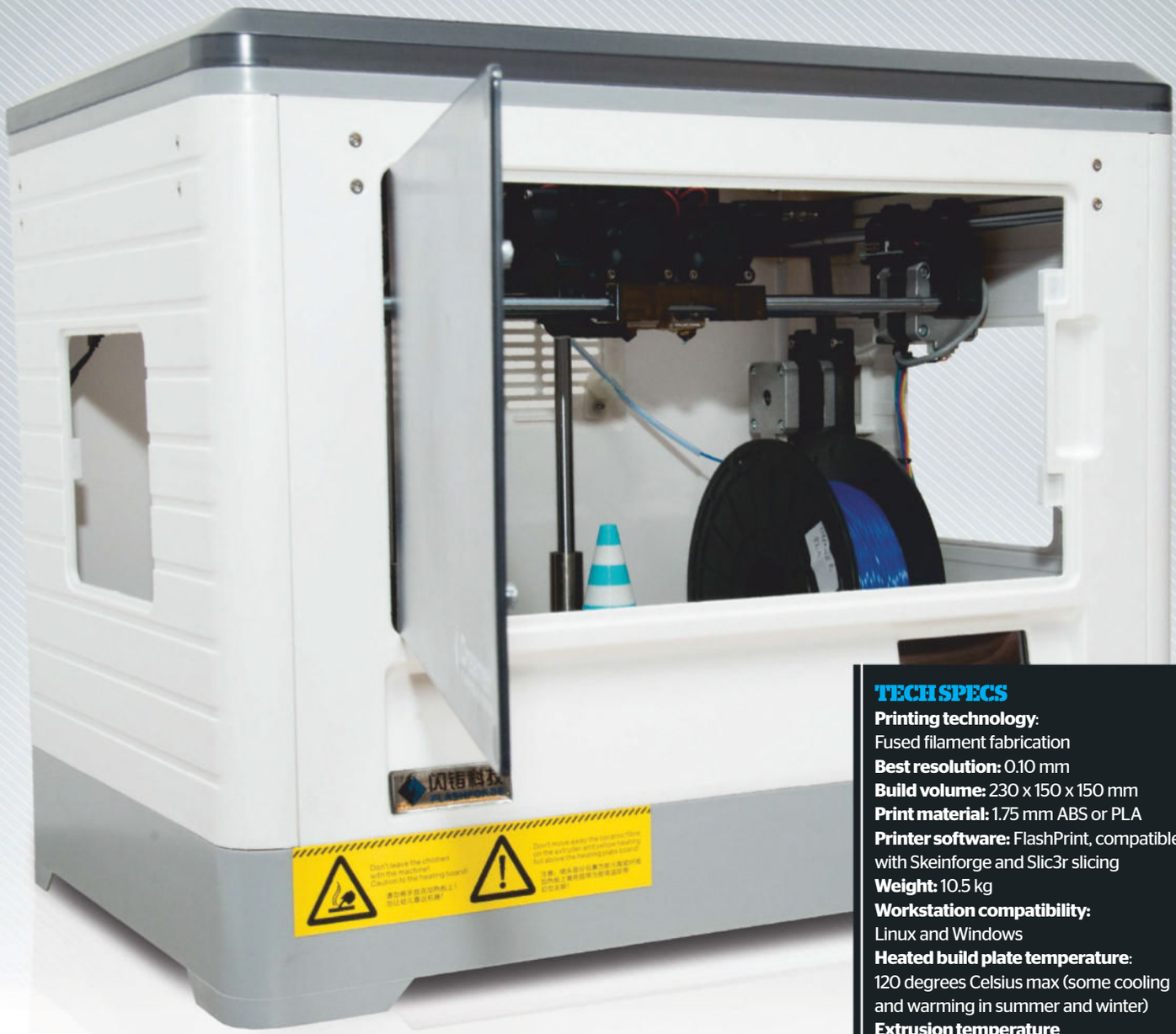
A few years ago, the advent of consumer 3D printing through initiatives such as Z Corp's Spectrum Z510, the RepRap project and MakerBot's Cupcake CNC kit inspired many in the industry to predict a revolution in the way we live – and create – for good.

Today, the 3D printing revolution they were waiting for has truly begun. Local Motors has designed the Strati – the world's first fully-drivable, 3D-printed car made up of 212 layers, while in China construction firm WinSun Decoration Design Engineering has 3D-printed a five-story residential building in a matter of months. In the meantime, bioprinting company Organovo has even announced that its 3D-printed liver tissue is now commercially available – an important first step towards producing whole human organs using 3D printing technologies.

In the world of consumer desktop 3D printers, things have also seriously changed. "Other than the constant improvements in speed and quality, I think the development of new materials is what I am most excited for," explains Rees Calder, marketing manager at the world's largest 3D printing store, iMakr. "Already we are seeing desktop 3D printers being able to print in wood, carbon fibre, elastic, copper and bronze composites, but I think filament manufacturers have only just scratched the surface."

With more desktop 3D printers, types of filament and extrusion technologies than ever before to choose from, we've teamed up with Rees and the other experts at iMakr for a closer look at five of the best 3D printers available today to take your designs from the computer screen to the physical world.

Contributors from iMakr
Rees Calder, Kirby Downey



TECH SPECS

Printing technology: Fused filament fabrication
Best resolution: 0.10 mm
Build volume: 230 x 150 x 150 mm
Print material: 1.75 mm ABS or PLA
Printer software: FlashPrint, compatible with Skeinforge and Slic3r slicing
Weight: 10.5 kg
Workstation compatibility: Linux and Windows
Heated build plate temperature: 120 degrees Celsius max (some cooling and warming in summer and winter)
Extrusion temperature 230 degrees Celsius max

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- **£999 at iMakr, with an additional discount at iMakr for the education sector at £499**

If you've never owned a 3D printer before but have always wanted to try one, the Flashforge Dreamer Dual Extruder is the ideal way to start.

Coming fully assembled right out of the box, the Flashforge Dreamer is impressively easy to set up and start printing with straight away, even if you are a complete beginner. The method for uploading a 3D print file is the perfect example; whereas many other printer types only give you one option to be able to transfer your model from computer to printer, the Flashforge Dreamer comes with support for everything from a 2 GB SD card included in the Dreamer box to USB and even built-in Wi-Fi with which to upload the printing file.

Then, once a print job has started, the Dreamer also features a convenient LCD screen to keep users informed about the build progress. This can also be done wirelessly from the user's computer with FlashPrint, a Flashforge software that allows you to monitor the print as well as move the extruder to different locations and even start or stop a build.

Despite it's easy-to-use appearances, however, make no mistake – the Flashforge Dreamer gives quite a lot of freedom for more in-depth experimentation too. It's able to print with both 1.75 mm ABS or PLA plastic for a best resolution of 0.10 mm (100 microns), and can also print using two different colours with a dual printhead design. This is a huge advantage when improving on the accuracy of the final print because one printhead can extrude the build material while the other can fill in areas of overhang with supports.

With a clean design, durable aluminium print bed and an enclosed 230 x 150 x 150 mm build volume chamber, the temperature levels are kept consistent in order to reduce warping as much as possible. Even the two spools of filament are stored internally, which means that less dust and other particles will accumulate on the plastic and interfere with the final print quality, as well as making for a safer printer to use as all hot or moving parts are contained in the closed case.

Of course, this means you may be restricted when it comes to spool size, as larger spools will not fit inside the Flashforge Dreamer Dual Extruder. However, this can be easily corrected by simply feeding any bigger spools in from the outside, which is an operation that can be done safely by printing out your own spool holder from various online sources.

IN THE BOX

- **Flashforge Dreamer assembled 3D printer**
- **Power lead and power supply**
- **2 spools of filament (one ABS and one PLA)**
- **1 SD card**

THE WORKHORSE

ULTIMAKER 2

€1,895 excluding tax from Ultimaker's website **£1,819 including VAT at iMakr**

This mid-level printer, designed for both non-expert and expert users alike, is one all the professionals at iMakr very highly recommend. A truly consistent workhorse of a printer, the Ultimaker 2 is very modifiable and excellent when it comes to high-precision prints, such as moving parts, due to its 0.02 mm best resolution – that's an accuracy of just 20 microns!

Like the Flashforge Dreamer, the Ultimaker 2 comes with an easy built-in display on the front that enables users to communicate with the printer and help with setup, along with a radial scroll wheel to adjust speed and heat during printing. Connectivity is simple: just an SD card slot, since the USB port is only for firmware updates.

Despite carrying a price tag that may deter some potential buyers, the Ultimaker 2 looks well designed and reliable, with a heated glass print bed that can be removed for easy cleaning and a very generous 230 x 225 x 205 mm build volume for its size. It can print with a wide variety of file formats, including STL, OBJ, DAE and AMF, and once it is printing, the Ultimaker 2 also features a fast print rate at 49dBA. The Ultimaker 2 is also one of the quietest machines while printing of all those on the 3D printer market.

Renowned as being one of the best pieces of software to prepare models for printing, another huge advantage of the Ultimaker 2 is that it also works with the free open source Cura software package from the Ultimaker website. Designed with ease of use in mind and for Ultimaker compatibility, it's one of the most powerful ways to prepare for 3D printing in seconds.

TECH SPECS

Printing technology: Fused filament fabrication
Best resolution: 0.02 mm
Build volume: 230 x 225 x 205 mm
Print material: 2.85 mm ABS or PLA
Printer software: Cura
Weight: 11 kg
Workstation compatibility: Windows (7 and up), Ubuntu (12.04 and up), OS X (10.7 and up)
Heated build plate temperature: 50 degrees Celsius to 100 degrees Celsius
Extrusion (nozzle) temperature: 180 degrees Celsius to 260 degrees Celsius

IN THE BOX

- **Ultimaker 2**
- **1 roll of filament**
- **Glue stick**
- **Power supply and cable**
- **Glue stick**
- **Power supply and cable**
- **USB cable**
- **User manual**
- **Glass plate**
- **Grease**
- **Hex wrenches**
- **SD card**

THE HIGH-TECH PRINTER

ZORTRAX M200

- **€1,595 from the Zortrax official website**
- **£1,499 from the iMakr website**

The latest printer from small Polish startup Zortrax, the Zortrax M200 has very quickly become a firm favourite among many of the 3D printing enthusiasts in the community today.

Unlike machines such as the Ultimaker 2, the Zortrax doesn't make use of any open source solutions, instead working through dedicated software, firmware and even the company's own 1.75 mm Z-Filaments. This makes using the M200 a little bit more restricted, particularly if you don't have easy access to Z-Filaments or don't feel comfortable using the Z-Suite software. Looking at the final results coming out of the printer, however, it's clear that this pays off. Despite having an advanced resolution of 25-50 microns, the Zortrax M200's prints look like they are much higher in quality when compared to similar-resolution products from other machines.

This all comes down to the printer's amazing technology. A system of dual X and Y axes is used to lead the single extruder with high precision, and the quality of the printing greatly improves through the use of eight smooth rods. The M200 is fitted with an innovative autocalibration system that makes sure that the platform is levelled correctly every time and makes preparation minimal.

IN THE BOX

- **Zortrax M200 3D printer**
- **One Z-ABS spool – pure white**
- **Set of accessories**
- **Z-Suite Software licence**

TECH SPECS

Printing technology: Fused filament fabrication
Best resolution: 25-50 microns
Build volume: 200 x 200 x 185 mm
Print material: 1.75mm Z-Filaments
Printer software: Z-Suite
Weight 13 kg
Workstation compatibility: Mac OS X, Windows (XP, Vista, 7, 8)
Heated build plate temperature: 110 degrees Celsius (230 degrees Fahrenheit)
Extrusion temperature: 380 degrees Celsius (716 degrees Fahrenheit) max temperature

"DESPITE HAVING AN ADVANCED RESOLUTION OF 25-50 MICRONS, THE ZORTRAX M200'S PRINTS LOOK LIKE THEY ARE MUCH HIGHER IN QUALITY"

THE BUSINESS TOOL

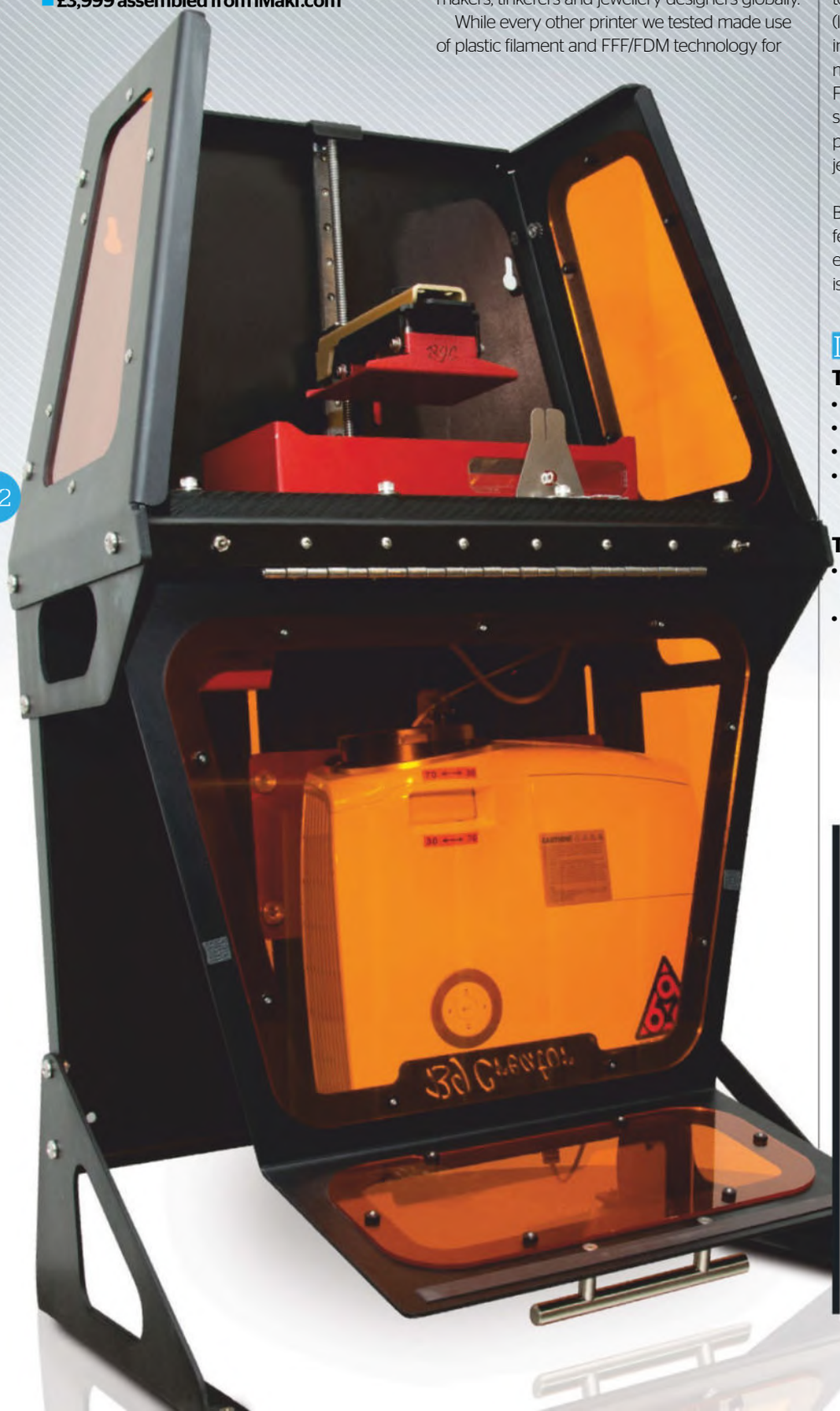
B9CREATOR V1.2

- **$5,243.40 assembled (non-US delivery)**
- **$4,882.80 assembled (US delivery)**
- **$3,985.20 Kit (non-US delivery)**
- **$3,707.60 Kit (US delivery)**
  – all from official site
- **£3,999 assembled from iMakr.com**

Don't let that price tag scare you away! Successfully funded on Kickstarter in 2012, the unique selling point of the B9Creator is that it's not just for experienced hobbyists but artisans too. It's been used by makers, tinkerers and jewellery designers globally.

While every other printer we tested made use of plastic filament and FFF/FDM technology for depositing plastic models onto a build platform layer by layer, the B9Creator actually used a completely different technology in order to produce its finished prints. The printer uses a powerful Digital Light Processing (DLP) projector to shine an image onto a layer of photopolymer (light-initiated) resin. The entire layer is then cured into a solid, enabling a resolution as fine as 30 microns at much faster printing rates than FFF/FDM machines. The results are cheap, supercomplex tiny objects like never before – perfect for getting into the business of casting jewellery, for example.

Compatible with Mac, Windows and Linux, the B9Creator is also fairly easy to use and assemble, featuring a USB connection to transfer STL files easily to the printer and a basic software suite that is free to download from **http://b9creator.com**.



IN THE BOX

THE ASSEMBLED VERSION

- **One complete unit, ready to calibrate and print**
- **One litre of B9R-1-Red resin**
- **One extra precoated vat**
- **Phone support in English for your first print job (one hour)**

THE KIT VERSION

- **Every part you will need to assemble a working B9C – but no resin**
- **Your vat will be coated with an initial PDMS layer but you will need to acquire the material to recoat it (Sylgard 184), which can be sourced by visiting www.amazon.com**

TECH SPECS

Printing technology DLP
Best resolution Up to 30 microns
Build volume x: 102.4 mm, y: 76.8 mm – volume varies, depending on resolution
Print material Resin
Printer software Available as a free download from **http://b9creator.com**
Weight about 13.5 kg
Workstation compatibility OS X, Windows, Linux
What controls the printer hardware The hardware is controlled by the included Arduino Uno with a custom shield. A host computer (not provided) drives the printer via a USB connection with the printer's Arduino. Video output from the host computer is fed to the printer's projector via VGA or HDMI connection

THE BIG PRINTER

DELTAWASP

- **€2,370 excluding tax on the official website**
- **£2,249 including VAT at iMakr**

Developed by Italian company Wasp, whose founder has also been working on creating a 3D printer capable of building a clay house for almost zero cost, is the DeltaWASP 20x40.

One of the defining features of the DeltaWASP is highlighted by the numbers included in the printer's name: a huge cylindrical build volume with a 20 cm diameter and 40 cm height. This makes it great for big prints, enabling users to print large objects at home without worrying about having to divide each model STL into separate parts that then need to be glued or slotted together in order to fit after printing.

The DeltaWASP also gives an exciting amount of choice when it comes to printing materials, as it's able to create using traditional PLA and ABS filaments as well as nylon, elastic polymers, polystyrene and Laywood – perfect to experiment on with bigger prints such as statues. The machine's body is well built and good-looking, made of aluminium and polycarbonate with a glass plate that will enable heat to be kept inside the printer to avoid warping or shrinkage.

A recent firmware update has also added great features such as Resurrection, which 'saves' your print so that even if interrupted by something like a power cut, the machine is able to restart printing again exactly where it left off.

IN THE BOX

- **3D printer assembled**
- **A glass bed**
- **Spool holder**
- **Power supply**

TECH SPECS

Printing technology Fused filament fabrication
Best resolution 50 micron, x y axis resolution 12 microns, z axis resolution 5 microns
Build volume 200 mm diameter and 400 mm height
Print material 1.75 mm PLA, ABS, nylon, elastic polymers, polystyrene, Laywood
Printer software Any open source: Cura, Slic3r, Repetier-Host and so on; software settings are available to download from **www.wasproject.it/w/en**
Weight 20 kg
Heated build plate 100 W heated floor

THE PRECISION PRINTER

FORM 2

€3499 on the Formlabs official website for the Form 2 Complete Package

Formlabs' Form 2 is a printer that truly stands out as being faster to set up than the rest – unlike most other desktop machines, there is no calibration needed for the Form 2 to work, meaning that you can really get set up and running in as little as 15 minutes.

This is largely down to the particular process the Form 2 uses to print: Stereolithography. Able to outperform the print quality that most FDM printers are capable of achieving with a best resolution of just 25 microns, SLA is a process whereby a high precision system directs a laser across a tray of liquid resin, causing a thin layer to solidify under the laser.

Traditionally only the domain of high-end, hugely expensive professional machines, stereolithography has recently become available to individual designers too thanks to printers such as the Form 2. This means the Form2 is not just easy to use but also able to print out very high-quality, high-resolution prints, even at very tiny sizes, making it a perfect tool for anyone looking to create incredibly precise models.

The printer's liquid resins, which replace the traditional ABS or PLA filament that most FDM desktop printers use, are more expensive at €135 a litre and they also come in a slightly more restricted variety of colours compared to what you might expect from plastic filament; however they provide for a wider variety of options for truly professional prints. The Castable resin, for instance, burns out cleanly with no ash or residue – perfect for capturing high-resolution prints through investment casting. In a step up from the Form 1+, the Form 2 heralds a self-heating resin tank which allows you to achieve optimal print conditions by maintaining a consistent temperature of 35 degree Celsius.

Using more than one colour resin, however, requires you to buy a separate resin tank for the printer. Resin tanks also wear with use and need to be replaced periodically, typically after being used with 2L of resin, so the running costs of this printer are a little higher than the others.

IN THE BOX

- **Form 2**
- **Self-Heating Resin Tank**
- **Build Platform**
- **Finishing Kit**
- **Free PreForm Software**
- **1 litre of resin of your choice**
- **One year warranty**
- **Hex wrenches**
- **SD card**

"A HIGH PRECISION SYSTEM DIRECTS A LASER ACROSS A TRAY OF LIQUID RESIN, CAUSING A THIN LAYER TO SOLIDIFY"

TECH SPECS

Printing technology Stereolithography
Best resolution 25-200 microns
Build volume 145 x 145 x 175 mm
Print material Methacrylate Photopolymer Resin
Printer software PreForm Software
Weight 13 kg
Workstation compatibility Windows (7 and up), OS X (10.7 and up)
Operating temperature Autoheats to 35 degrees Celsius

3D PRINTER ROUND-UP

	FORM 2	DELTAWASP	B9CREATOR V1.2	ZORTRAX M200	ULTIMAKER 2	FLASHFORGE DREAMER DUAL EXTRUDER
WEIGHT	13 kg	20 kg	13.5 kg approx	13 kg	11 kg	10.5 kg
BUILD VOLUME	145 x 145 x 175 mm	200 mm diameter, 400 mm height	X: 102.4 mm, Y: 76.8mm - build volume varies, depending on resolution	200 x 200 x 185 mm	230 x 225 x 205 mm	230 x 150 x 150 mm
COST OF OFFICIAL MATERIALS	From €90 to €135 for 1 Litre	From €35 per 1 kg spool	From £107 per 1 kg bottle	From €27 to €39 per spool	From €31.50 excl. VAT	On sale at time of writing from $29 to $34
COST OF PRINTER	€3,399 excluding VAT at FormLabs.com	£2,249 including VAT at iMakr	£3,999 assembled from iMakr.com	£1,499 from the iMakr website	£1,819 including VAT at iMakr	£999 at iMakr
RESOLUTION	25-200 microns	50 microns, x y axis resolution 12 microns, z axis resolution 5 microns	Up to 30 microns	25-50 microns	20 microns	100-500 microns
MATERIALS	Resin	1.75 mm PLA, ABS, nylon, elastic polymers, polystyrene, Laywood	Resin	1.75 mm Z-Filaments	2.85 mm ABS or PLA	1.75 mm ABS or PLA
PROS	Stereolithography makes for professional, precise high-res prints even at small sizes	Huge build volume, very wide range of printing materials	DLP technology perfect for high-resolution professional prints	In-house tech for better resolution than other comparable printers	Well-established brand, great resolution	Cheap to buy , dual extruders and good range of materials
CONS	High cost of materials and Resin tank needs replacing regularly	Pretty expensive printer, heavy so not as portable	Expensive, high cost of materials and not much material choice	Completely closed tech and software, even filament is the brand's own	Pretty high-end price, only SD slot available to upload models to printer	Resolution isn't as good as the others we've reviewed here

CHOOSING FILAMENTS

Discover the differences between the diverse range of filaments available

ABS, or acrylonitrile butadiene styrene, is an oil-based, flexible material with a higher melting point than PLA. Suitable for parts exposed to high temperatures after printing, it's dissolvable in acetone and enables users to smooth out surfaces for a high-gloss look and even glue parts together. ABS can warp as it expands and shrinks during heating and cooling. Using a heated build plate with it in an enclosed chamber is preferable.

PLA, or polylactic acid, is a biodegradable polymer, so more environmentally friendly than ABS. It's dimensionally stable, so there is normally no need for a heated bed. PLA produces a naturally glossy, strong, nontoxic print, but it's also more brittle, so may not be useful for functional parts. PLA is often preferred for at-home 3D printing due to its low warping, sharper printed corners, lower layer heights, better smell and faster printing speeds.

SPECIALIST FILAMENTS

Glow in the Dark is a filament that looks white in the day and glows at night. **Buy it** FormFutura EasyFil PLA Glow in the Dark

Colour Changing is a filament that changes colour according to temperature. **Buy it** FormFutura Thermochrome EcoPLA

Wooden combines plastic and recycled wood fibres for a wooden finish or even smell. **Buy it** ColorFabb WoodFill, ColorFabb bambooFill, EasyWood Coconut

Metallic is made up of metals, making it heavier with a metal smell. These prints need to be sanded and polished to shine. **Buy it** ColorFabb BronzeFill

Ceramic is still experimental, but you can create prints that can be fired to hard pottery with clay-based 3D filament. **Buy it** Lay-Ceramic

Carbon fiber is made from PLA Resin compounded with 15 per cent chopped carbon fibres, designed to be stiff and resist bending. **Buy it** Proto-Pasta Carbon Fiber

Flexible Filament is a special thermoplastic elastomer, producing flexible prints with elastic properties. Most 3D printers will need minor Flexible Filament modifications so that it extrudes well and doesn't buckle. **Buy it** NinjaFlex

Nylon is a stronger, flexible and more durable alternative to PLA and ABS but has the tendency to warp. **Buy it** Taulman 3D Bridge Nylon, Nylon 618, Nylon 645

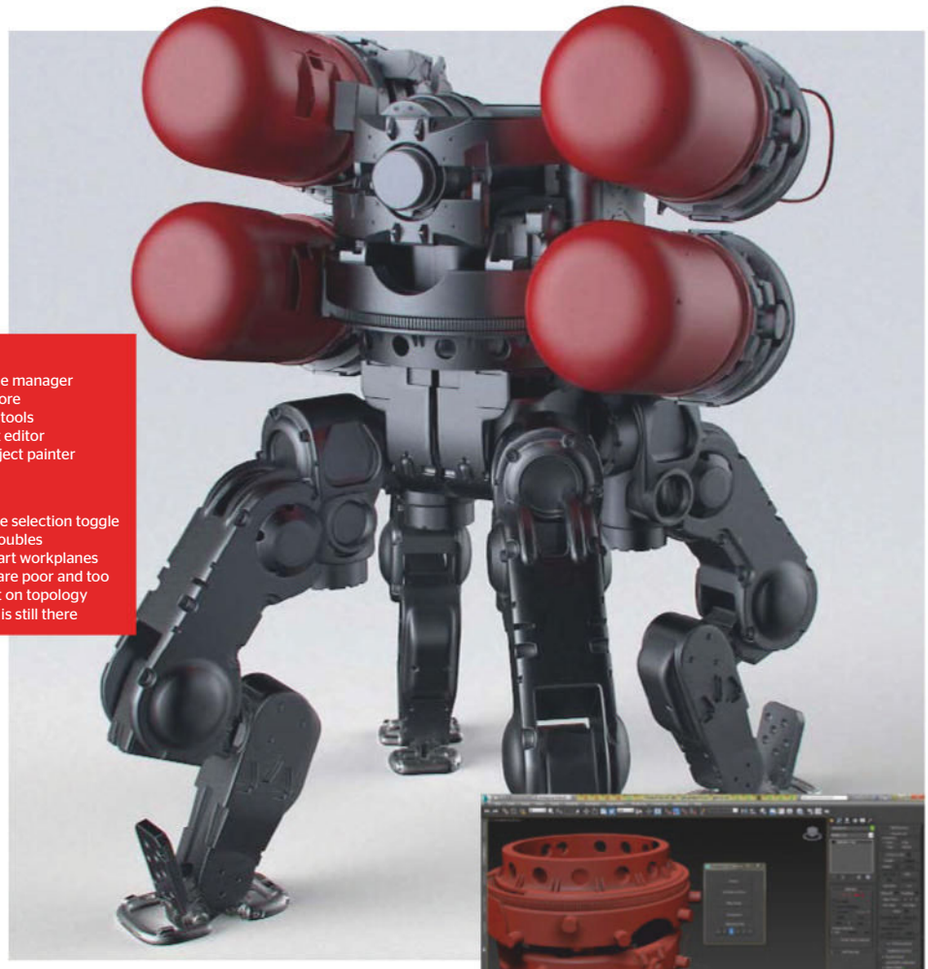
PVA is a cold water-soluble material that is extremely suitable for supports for complex ABS or PLA prints. **Buy it** Formfutura AquaSolve

MODELLING SOFTWARE ROUND-UP

Discover the very best software available for making print-ready models and consider investing

3ds Max 2015

3ds Max has a reputation for awesome tools, render engines and core tools. Does it hit the sweet spot for 3D printing too?



BELOW This is an example of a rendered mech model assembled in 3ds Max 2015

Speed is a vital consideration for anyone looking to model for 3D printing, and the first important change in 3ds Max 2015 is the massive improvement of the viewport speed. The new Nitrous viewport enhancements are excellent, and as a result the viewport performance can now smoothly handle far more poly and vertices per model along with a superb amount of triangles, making modelling much more stress-free. Autodesk has also fixed AA performance; edges are bold and easy to see, and the selection lag between heavy meshes has been reduced.

The core modelling tools have also been updated, an important enhancement to anyone interested in modelling for 3D printing. The new Quad chamfer modifier, for example, allows users to set the type of chamfer generation and detach options if you want the open chamfer option ticked on. It can be detached from the mesh and inverted if needed, which can lead to some remarkably accurate layouts.

PROS
- ▲ Good scene manager
- ▲ Updated core modelling tools
- ▲ Faster mat editor
- ▲ Superb object painter

CONS
- ▼ Poor isolate selection toggle
- ▼ Shading troubles
- ▼ Still no smart workplanes
- ▼ Chamfers are poor and too dependent on topology
- ▼ Egg spline is still there

Another amazingly progressive feature is great for people looking to scan objects for 3D printing, as opposed to just modelling from scratch: the ability to import point cloud data – including colour data – into a 3ds Max scene. This means that it's a straightforward process from importing point data through retopology to arrive at a clean, print-ready 3D model.

Unfortunately, there are still some major annoyances with 3ds Max when it comes to a 3D printing workflow. For example, when importing multi-part meshes you have to import each file separately, which can take a lot of time. Is it so hard to implement an additive selection to the importing algorithm? Also, SAT files are still displayed just as badly as before when you convert them into editable poly objects.

We also discovered that the toggles you need to use to isolate selections don't work by default; they require a hotkey to be set up manually. This doesn't exactly create a smooth workflow.

There are definite speed improvements in 3ds Max 2015, but it's strange that Autodesk hasn't included features such as parametric chamfer, workplanes, smart importing and adaptive workspaces (or at least a floating viewport).

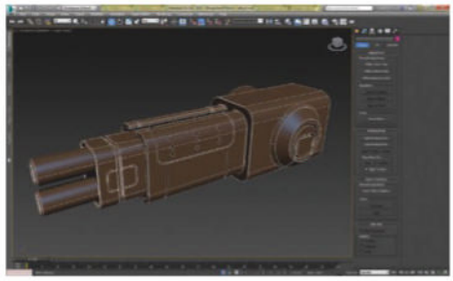
Essential info

Product	Autodesk 3ds Max 2015
Price	From £3,100 / $3,675 US (subscription available)
Website	www.autodesk.com
Operating systems:	Windows 7+
CPU Type	Intel Xeon/Pentium 4, AMD Opteron/Athlon 64
Memory & Storage	8 GB RAM, 6GB HDD

Summary

3ds Max is a leading software in multiple fields including 3D printing and modelling, and every release is slightly better than the last one.

ABOVE 3ds Max has some great options for placing and orientating your models



ABOVE While not completely optimised for 3D printing, there are plenty of powerful tools for you to model with

Rhinoceros 5

Rhinoceros is a NURBS modelling software, which at its core is a pure-blood CAD program for drafting, prototyping, modelling and rendering

Rhinoceros can be described as a CAD software on steroids. Besides offering the basic CAD functions that people got used to in AutoCAD and others, it brings you an amazingly wide variety of 3D modelling features perfect for print-ready results. Anyone can do boxes and spheres, but Rhino succeeds in the areas where other software competitors usually fail, for example giving you flawless booleans. Being sure your booleans will come out perfectly means you are free to handle any modelling task with ease.

The advantages of using NURBS for modelling is mostly in their precision. Whether you set your units to light years or microns, Rhino will give absolutely perfect results, so you can always rely on it in any situation.

For example, architectural visualisation studio FlyingArchitecture tells us they started using Rhino back in 2007 as a drafting and modelling software for architecture. They got into 3D printing as their market grew and their clients began to demand more and more additional services. Thanks to their friend at **www.najlacnejsia3dtlac.sk**, they could easily offer clients 3D-printed versions of visualised projects.

NURBS is not very typical for arch-vis, but Rhino proved itself as being more than suitable even for these traditionally very creative fields. Preparing models for arch-vis did not give FlyingArchitecure any limitations when it came to changing their workflow whenever needed. Plans and sections could be added with a simple click. Models needed for rendering could be generated incredibly quickly, as could the data for 3D printing.

So Rhino offers effective tools for 3D printing: it works with a command line, so you can directly write commands (or their modifications – and Rhino will suggest things to help) to quickly proceed to specific functions. Analysis, reparation, checking, rebuilding, filling holes... it's all done with a single click. Using it actually gives you the feeling that Rhino was born for 3D printing years before it became mainstream.

CASE STUDY

FlyingArchitecture took their previously finished 3D model of a floating family house with a Voronoi facade and turned it into a working lamp in a single day. The finished print had rock-solid construction, tight and exact gaps, and they could dim the light inside the object smoothly.

As a first step, they checked that everything was correct with the model. The simple command 'What' will give you precise information on the model. Yes, you ask 'What?' in Rhino and it will give you a report. Amazing, right?

BELOW FlyingArchitecture as a company provides visualisation services, but with the help of Rhinoceros it can bring you a flying house as a ceiling light for your office

PROS

- ▲ Nice mesh topology
- ▲ Advanced mesh tools
- ▲ Automatic mesh fixing
- ▲ It's absolutely precise

CONS

- ▼ Missing retopo features
- ▼ Should have even better mesh support

If there are any problems with your model then you will be notified, and using simple commands like Repair Mesh, Analyse, Fill Hole and Cap you can fix the model in a matter of minutes.

FlyingArchitecture's arch-vis model was turned into a 3D-printable, watertight model immediately, enabling them to play with features like an LED slot, a place for the battery, various combinations of materials and so on. The model was printed in a day or so and could then be used straight away as a lamp for a child's bedroom. With Rhino, the whole process was amazingly simple.

Essential info

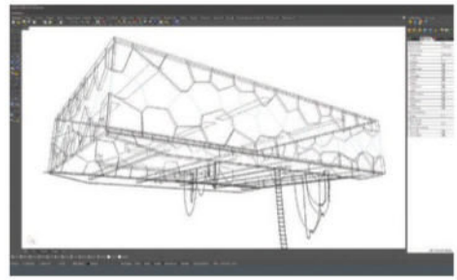
Product	Rhinoceros 5
Price	£720 / $1050 US
Website	www.rhino3d.com
Operating systems:	Windows 7+
Video	OpenGL 2
Memory & Storage	8 GB RAM, 1GB HDD

Summary

Rhino is extremely easy to use and is suitable to replace any CAD/modelling software currently being used in your studio. Just give it a try.

ABOVE Besides being extremely user-friendly for beginners, Rhino is a mighty tool for any professional in the industry

ABOVE Providing a possibility of a command line, Rhino is a great tool for anyone in need of a precise, stable modelling software



ABOVE You can get very fine control over the display options inside the Rhino interface

ZBrush 4R7

The beloved software of 3D modellers the world over – does ZBrush deserve to be loved or left?

PROS

- ▲ Easy to use box-modeling features
- ▲ Dynamesh for regenerating even quads for iterative sculpting
- ▲ Dynamesh for hollowing out via Create Shell option
- ▲ Decimation Master for polygon reduction
- ▲ 3D Print Exporter for STL export

CONS

- ▼ Need for a real 3D coordinate system with a specified unit of measurement
- ▼ Individual subtool control at component level
- ▼ Could use key/slot IMM brushes
- ▼ Ability to slice, generate and visualise G-Code would be nice

ZBrush 4R7 is out, and the newest feature that has taken the modelling world by storm is the ZModeler brush. This allows for box-modeling functionality right inside ZBrush, along with the ability to control geometry at the vertex, edge and face level. For the TikiBot character pictured to the right, a base mesh of a Sketchbot designer toy was the starting point. Pieces were kept separate, knowing they would be exported as STLs for 3D printing. The Dynamesh was employed too extensively to re-project a fine grid of polygons that could accommodate finely sculpted detail – in this case, the small cracks and pits that would represent a pseudo wood-grain effect.

Once all of the subtools (12 for this particular character) were fleshed out, the next step involved generating keys and slots for the all the pieces to be able to connect together once printed, similar to a model kit. This involved masking off regions that would be pulled out to form the positive key, duplicating the piece and using it as a negative shape for a subtractive boolean operation. With the exception of the wrist connector, which needed to be a perfect cylinder that would enable rotation, one important tip is to taper your keys for easier connectivity.

The next step was to go through all of the geometry and decide which pieces could be hollowed out. This will help save costs of material when choosing a 3D print service bureau. ZBrush has an excellent feature in the Dynamesh tool that will create a user-specified shell thickness based on a boolean cut. Our expert reviewer Steve Talkowski has provided a YouTube video for a more detailed explanation: **bit.ly/1FGNIZS**.

When it comes to reducing the poly count prior to STL export, ZBrush provides yet another excellent plug-in: the Decimation Master. This will analyse your geometry and perform a poly reduction based on a user-specified percentage. What you get is a nicely triangulated result that gives you finer triangles where detail is needed, and much larger triangles that cover broader areas that don't require high-density coverage.

The final step is to export your STL. Using the 3D Print Exporter plug-in, you can specify the dimension in one axis, and it will then update the size ratios for the other two axes. Select inches or millimetres, then click on STL to export out the selected piece, which you can now import into your printer's slicing software in order to generate the corresponding G-Code.

With the release of ZBrush 4R7, Pixologic has teamed up with Keyshot to provide users access to an amazing renderer at a very minimal cost of entry point, which is perfect for 3D printing.

BELOW TikiBot generated from a base mesh and split into 12 unique subtools for 3D print output

ABOVE Many modelling projects require at least a passing use of ZBrush to refine key areas before the model is sliced

ABOVE ZBrush is ideal for sculpting organic components in your design to get exactly the look that you want in your print

Essential info

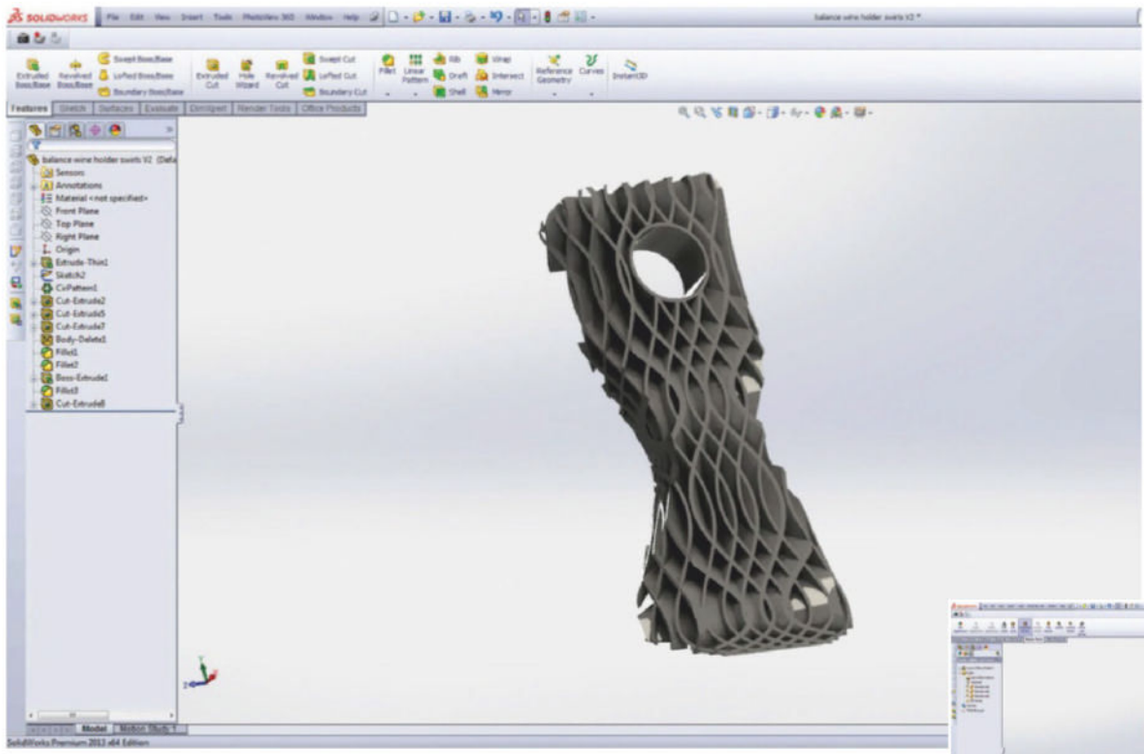
Product	ZBrush 4R7
Price	$795 US
Website	www.pixologic.com
Operating systems:	Windows Vista+, OS X10.7+
CPU Type	Intel Pentium D/Macintosh, AMD Athlon 64 X2
Memory & Storage	6 GB RAM, 16GB HDD

Summary

Continued improvement on an already impressive feature list. Looking forward to GUI enhancements and precise subTool control in the next release.

SolidWorks

SolidWorks is the most popular CAD software available and used in a wide range of industries from product design to mechanical engineering



LEFT The SolidWorks interface displaying the real view graphics

PROS

- ▲ Easy to learn
- ▲ You can edit your history
- ▲ Create dimensional-accurate parts
- ▲ Test your joints and moving parts before sending to print

CONS

- ▼ Can't go too organic with your models

One of the most enjoyable aspects of SolidWorks is its ability to surprise you with new things. It is a program that enables you to create accurate 3D models that can be exported for print without any errors on the STL file. Essentially, SolidWorks is a solid body modelling software at heart that also has the capability for surface modelling.

If you are designing a model with multiple parts, you can test your fitting with the Assemble feature. This enables you to build the object inside SolidWorks and test the tolerance of the fittings and see if everything lines up. If you have moving parts in the object, SolidWorks also enables you to test the moving mechanism to ensure the parts move smoothly and don't interfere with the main body of the object. You could go a step further with SolidWorks and test the tensile strength of an object when a certain amount of force is applied to it. Testing these feature can save a lot of time when printing to find that the parts don't fit.

SolidWorks has an integrated rendering software called Photoview 360. This render tool has similar capabilities to Keyshot, and enables you to create a realistic final rendering of your objects as well as apply them to real scenes. SolidWorks also has the room to create animations, from simple rotations of your model to full exploded views and parts moving.

The only downfall to using SolidWorks is its inability to import files. It can import certain files but doesn't do this well.

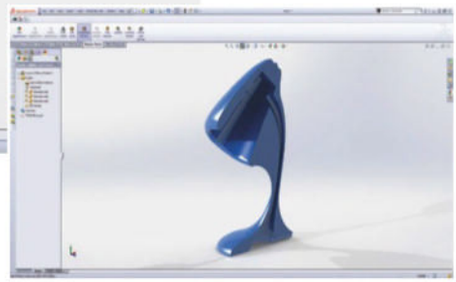
Other than that, it is a great software to use and easy to get into. The commands are all in the top bar – they are illustrated with images, so you can see what everything does. SolidWorks also comes with tutorials to get you started; these run with SolidWorks, so if you need to use a new command and you don't know where it is then you can click on the tutorial. SolidWorks will then react and highlight the button to use the command. It's a user-friendly software with an interface that is as intuitive and basic as possible.

Essential info

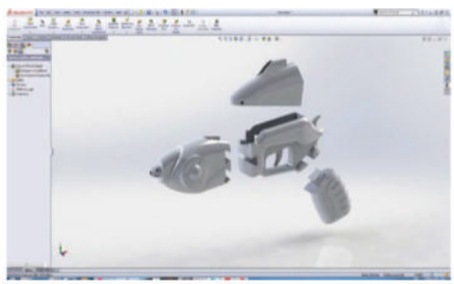
Product	SolidWorks 2015
Price	$3995 US
Website	www.solidworks.co.uk
Operating systems:	Windows 7+
CPU	Intel/AMD with SSE2
Memory & Storage	8 GB RAM, 5GB HDD

Summary

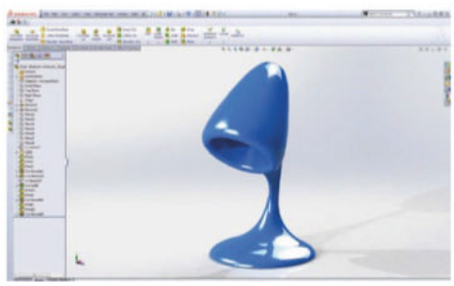
SolidWorks is an easy-to-use software with a great range of commands to help you create many different kinds of objects.



ABOVE You can section your model to see how it will all look on the inside to ensure you are happy before you send to print



ABOVE In assemblies you can elaborate on how to assemble you model with the exploded view feature



ABOVE SolidWorks includes a large bank of ready-made features that you can add to your product designs

AutoCAD 2015

Traditionally an architect's design tool, AutoCAD has developed into a program at the forefront of 3D printing

PROS
- ▲ Versatile
- ▲ Ability to work to precise scales
- ▲ Clean, accurate models
- ▲ Extensive tools
- ▲ Dedicated 3D print to service button

CONS
- ▼ Steep learning curve
- ▼ Complicated interface
- ▼ Mesh and NURBS support unfavourable

AutoCAD is fundamentally a 2D drafting program and, as a result, a great deal of its power remains within the tools that are geared towards drawing orthographically. Yet over the last few versions it has been extended to enable the generation of geometric 3D models quickly, accurately and efficiently, culminating in the ability to print in 3D.

For the average user, 3D modelling will begin in much the same way as drawing two-dimensionally. For those more versed in solid modelling, the recent support of 3D primitives and powerful boolean tools all assist in creating parametric objects instantly and easily without the fuss of outlining everything first. If you are someone that favours the latter, you will soon discover that the tools which are dedicated to producing detailed schematics can now be utilised to create 3D models that are clean, precise and watertight, albeit something of a headache to work up.

Aimed primarily at professionals, AutoCAD is complicated and can take a lot of time to learn. Needless to say, finding your way around is much easier than it used to be. The 'Ribbon' it uses to group common tools together redirects the user from the once mainstay command line, towards that of an application more proficient in 3D modelling and print. A dedicated 'Send to 3D print service' button has even been introduced to offer help, scale your model and export to STL format. Yet despite the convenience of all this, if you're unfamiliar with this style of interface then it can feel quite daunting and take some getting used to.

Regardless of its interface, AutoCAD has remained and always will remain an essential application in 3D printing. As an architectural CGI artist, generating a complex architectural model may require printing certain elements separately. Using tools such as the advanced UCS control, comprehensive layer management, extensive snap settings and accurate polar tracking, it is possible to adapt each element to slot together tightly and perfectly like a jigsaw. In just the same way, users can make accurate allowances between certain parts to produce models that move.

Since the dawn of 3D printing, AutoCAD's application has gone a long way beyond its original purpose. Its ability to offer an exceptional level of precision, coupled with the ability to draw to scale, allows the engineering of objects that are accurate to a fraction of a millimetre.

Despite this, there is one major downside if you are hoping to build and 3D-print something that is more organic. NURBS and mesh modelling offer support but they lack refined workability and they also require a lot of preparation. For that reason, if you are a beginner to AutoCAD then you will find that more function-dedicated programs can perform that task far better, simpler and faster than AutoCAD.

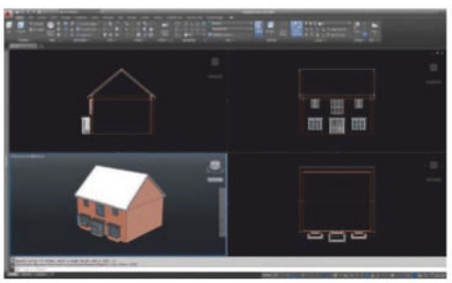
BELOW An accurate, scaled architectural model, constructed and printed within AutoCAD 2015

Essential info

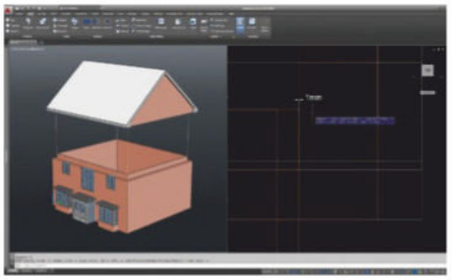
Product	AutoCAD 2015
Price	£1,520/year (subscription) / $1,680/year (subscription) US
Website	www.autodesk.co.uk
Operating systems:	Windows / Mac
CPU Type	Intel/AMD Athlon 3.0 GHz + with SSE2
Memory & Storage	8 GB RAM, 6 GB HDD

Summary

It is a difficult program to grasp at first, but when it comes to precise geometric models it really is quite hard to beat AutoCAD.



ABOVE The interface has had a remodel over the last few versions – new users may not find it particularly friendly



ABOVE The precision to draw and model to within a fraction of a millimetre makes AutoCAD an unrivalled application

Blender

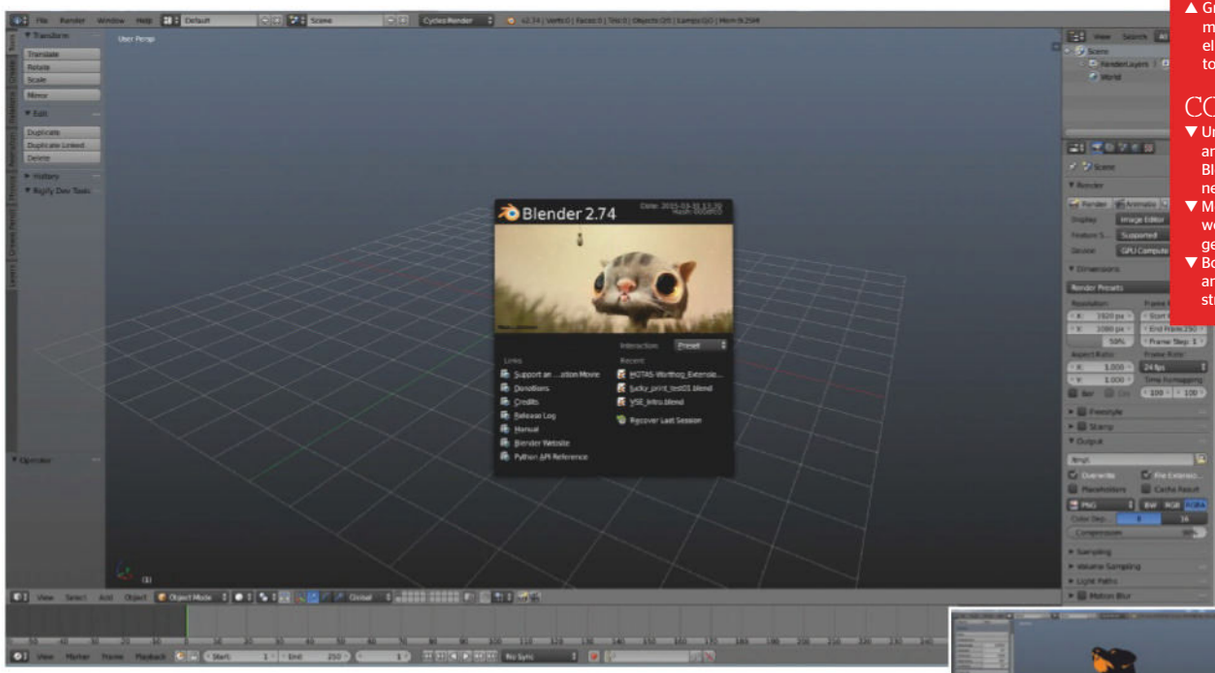
Blender is an incredibly powerful software and an invaluable addition to any 3D printing enthusiast's digital toolbox

PROS

- ▲ Free and open source
- ▲ Extensive modelling feature allowing for both polygon modelling and sculpting
- ▲ Hotkey-based tools allow for a fast workflow
- ▲ 3D print toolbox checks for printability issues
- ▲ Great for cleaning up models, reducing or eliminating the need for tools like Netfabb

CONS

- ▼ Unusual user interface and commands mean that Blender is difficult for the newcomer
- ▼ Mesh modelling means worrying about keeping geometry manifold
- ▼ Booleans can be slow and sometimes produce strange results



LEFT The Blender 2.74 splash screen and default scene. The UI has been tweaked and is very customizable.

Blender is one of those programs that people seem to either love or hate. However, considering its price point and sheer number of features, there's no arguing that it's powerful.

Blender is, at its core, a mesh-modelling application with an extensive tool set allowing for any number of workflows. Box modelling from a cube is easy, as is poly-by-poly modelling. A sculpting workflow is also supported, with the option to have the program dynamically re-create the underlying mesh structure at varying levels of detail as you work.

Blender makes heavy use of hotkeys, resulting in a very fast workflow once you learn the key combinations. This is usually not that hard, as many of them are fairly intuitive. The downside to this is that many of these tools are not presented on-screen, or are tucked away in tool shelves or menus. More recent releases have made strides towards remedying this, but the fact remains that Blender is often very intimidating to new users. Ease of use and UI design is a topic of contention within the Blender and larger 3D graphics community, and there's no getting away from the fact that Blender is not easy to learn. However, stick with it and you'll find it rewarding.

While Blender was not initially designed with 3D printing in mind, the development team has embraced the 'age of the 3D printer' and included a 3D-Print Tool Box add-on. This thing is absolutely fantastic; with a single click, your model will be checked for non-manifold geometry, overhangs, thickness and a number of other issues that could kill your print. It will display the number of instances of each error and highlight the offending geometry, allowing for quick cleanup.

Blender does feature some Boolean tools, enabling users to quickly join multiple meshes into a single printable object. These tools are also useful for splitting an object into multiple, smaller, more printable objects that can be assembled later. Unfortunately, Booleans can be finicky at times and are very slow when dealing with detailed models.

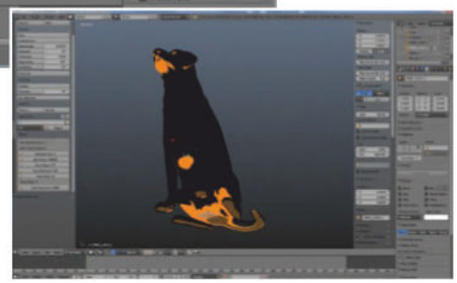
It's impossible to cover all the ways in which Blender aids a 3D printing workflow, or express just how great the software package is as a whole. Pick it up for yourself and watch a few tutorials to get yourself started. What do you have to lose? It's free, so it's almost silly not to install it.

Essential info

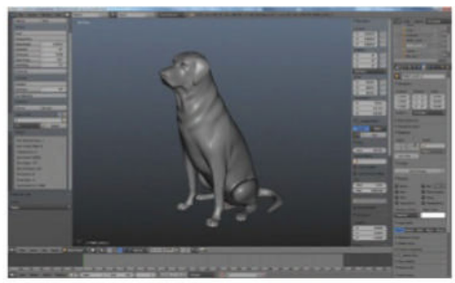
Product	Blender
Price	Free
Website	www.blender.org
Operating systems:	Windows 7, OS X 10.6, Linux
CPU	2 GHz with SSE2
Memory & Storage	8 GB RAM, 1GB HDD

Summary

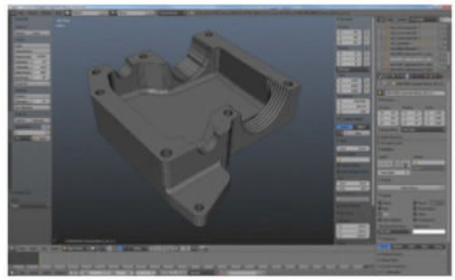
While a hotkey-based workflow and unusual user interface can turn newcomers away, Blender is a powerful tool for makers and artists alike.



ABOVE Creating sculptures that are ready for 3D printing from scratch is easy in Blender



ABOVE The 3D Print toolbox will highlight regions with overhangs, along with a number of other printability issues



ABOVE While usually the domain of CAD programs, complex mechanical objects can be made in Blender with a little work

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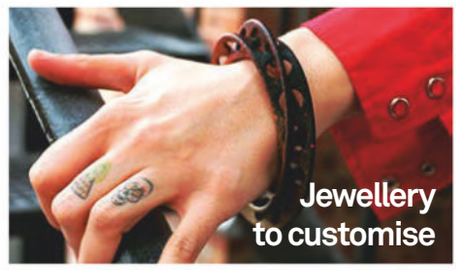

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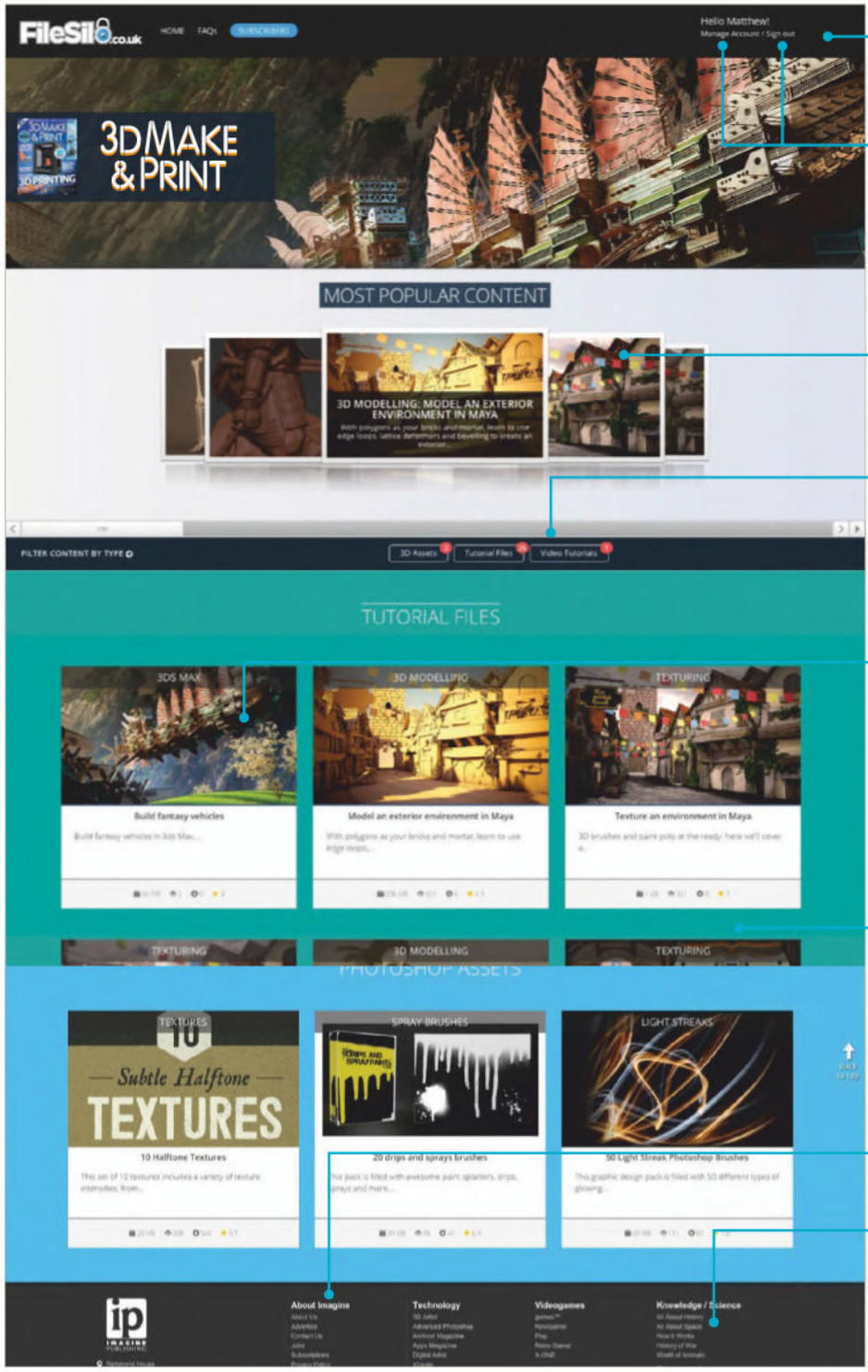

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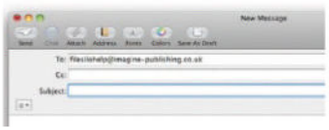

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